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FROM THE EDITORS

The collection of articles under the general title of *Psychological Research in the U.S.S.R.* is aimed at aquainting foreign readers with Soviet research in psychology and certain related disciplines. The articles were written at different times, deal with various problems and express different trends of psychological thought in the U.S.S.R.

To present an actual picture of Soviet psychological research, the authors preferred to compile this collection not from review articles, but from original works some of which were written more than ten and even twenty years ago. Most of them have been published and only a few articles which constitute the authors' summaries of their investigations were written especially for this publication. The articles are arranged according to a thematic rather than a chronological principle.

Of course, the content of this collection cannot pretend to give a complete picture of the psychological research conducted in the U.S.S.R. Many branches of psychology deserving of consideration are not represented in it at all. Others are represented but by few articles. However, the editors hope that the present publication will help the readers to get a sufficiently clear and, what is most important, an objective idea of Soviet psychology. Simultaneously with publishing this collection in English the Publishers have released a collection in French dealing with the following subjects:

1. Memory, thinking and speech.
2. Personality. Development and learning.

Professor *A. Leontyev*
Professor *A. Luriya*
Professor *A. Smirnov*

PART ONE

GENERAL PROBLEMS OF PSYCHOLOGY AND PSYCHOPHYSIOLOGY

DEVELOPMENT OF THE HIGHER MENTAL FUNCTIONS*

By L. S. VYGOTSKY

PROBLEM OF DEVELOPMENT OF THE HIGHER MENTAL FUNCTIONS

The history of development of the higher mental functions is an entirely unexplored field of psychology. Despite the enormous importance of studying the processes of development of the higher mental functions for the correct understanding and elucidation of absolutely all aspects of the child's personality the boundaries of this field have not been clearly marked, the investigators are not methodologically cognisant of the problems they are faced with and no appropriate method of investigation has been elaborated; nor have investigators outlined or developed the elements of a theory or at least a working hypothesis which might help them to comprehend and tentatively to explain the facts obtained and the regularities observed in the process of work.

Moreover, the very concept of development of the higher mental functions is still vague and unclear. It is not sufficiently differentiated from other closely associated and related concepts and its content is not definite enough.

It stands to reason that with things as they are it is necessary to elucidate the basic concepts, state the main problems and ascertain the objects of investigation.

The traditional views of the development of the higher mental functions are one-sided and erroneous primarily

* Abridged translation of L. S. Vygotsky's extensive work written under the same title in 1930-31. The complete work was published in L. S. Vygotsky's book *Development of the Higher Mental Functions*, Moscow, Publishing House of the R.S.F.S.R. Academy of Pedagogical Sciences, 1960, pp. 13-223.

Here and elsewhere all references are made to Russian editions unless otherwise stated.

and mainly because they are unable to see facts as facts of historical development, regard them as natural processes and formations, confuse them and fail to differentiate the organic from the cultural, the natural from the historical, the biological from the social in the child's mental development, in a word—these views of the nature of the phenomena in question are fundamentally incorrect.

The higher mental functions and complex cultural forms of behaviour with all the specific features of their function and structure, with all the specificity of their genetic development from appearance to complete maturity or extinction, with all the special laws by which they are governed, usually remained outside the investigator's field of vision.

Complex formations and processes were broken up into constituent elements and ceased to exist as a whole, as structures. They were reduced to processes of a more elementary order, occupying a subordinate position and performing a definite function with respect to the whole, part of which they formed. Like an organism which, broken up into its constituent elements, reveals its composition, but no longer displays its specifically organic properties and regularities, these complex and integral psychological formations lost their basic quality and ceased to be themselves when reduced to processes of a more elementary order.

Such an approach to the problem of the child's mental development was pernicious because the concept of development radically differs from the mechanistic conception which likens the appearance of the complex mental process from separate parts or elements to a sum forming from arithmetical addition of separate numbers.

Since this approach to the problems of development of the child's higher mental functions prevailed the analysis of the ready form of behaviour was, as a rule, replaced by elucidation of the genesis of this form. The genesis was often replaced by an analysis of some complex form of behaviour at various stages of its development so that an impression was created that not the form as a whole developed, but its separate elements, together forming at each given stage of their development a particular phase in the development of the given form of behaviour.

Under these circumstances the very process of development of complex and higher forms of behaviour failed to be elucidated and methodologically comprehended.

One of the most essential features of such an approach is that psychology has not as yet sufficiently firmly established the differences between the organic and cultural processes of development and maturation, between two genetic series differing in essence and nature, and, consequently, between two fundamentally different series of regularities which govern these two lines of development of the child's behaviour.

Child psychology—the older psychology, as well as that of our time—is characterised by an opposite striving, namely, to put all the facts of the cultural and organic development of the child's behaviour in one series and to regard them as a phenomenon of one order, one psychological nature, revealing fundamentally the same kind of regularities.

This is the result of refusing to study the specific regularities of one series, reducing complex mental processes to elementary processes and studying one-sidedly the natural aspects of the mental functions.

Old subjective psychology saw the main object of scientific investigation in singling out the primary, no further dissociable elements of experience, which it found through abstracting elementary mental phenomena, like sensation of pleasure, displeasure and volitional effort, or in similarly isolated elementary mental processes and functions, such as attention and association. The higher and complex processes were broken up into constituent parts; they were completely reduced to combinations of these primary experiences or processes of various complexity and form. This gave rise to a vast mosaic of mental life composed of separate pieces of experiences, an immense atomistic picture of the dismembered human spirit.

Nor does the new, objective psychology know any other ways of cognising the complex whole except analysis and dissociation, except elucidation of the composition and reduction to elements. Reflexology* closes its eyes on the

* By reflexology the author implies the conception which was very popular in the 1920s; this conception endeavoured mechanistically to reduce all of human behaviour to a simple combination of conditioned (combinative) reflexes. This point of view was clearly expressed in such works as V. M. Bekhterev's *Fundamentals of Reflexology*, G. A. Vasilyev's *Outlines of Physiology of the Mental Life*, etc. A very similar point of view was developed by American behaviourists (*Editor's note*).

qualitative specificity of the higher forms of behaviour; it makes no fundamental distinction between them and the lower, elementary processes. All processes of behaviour are broken up into chains of combinative reflexes differing in length and the number of links, in some cases inhibited and not revealed in their external part. Behaviourism operates with units of a somewhat different character, but if some units are replaced by others, if the reflexes are replaced by reactions in the reflexological analysis of the higher forms of behaviour, the resulting picture will very much resemble the one produced by the analyses of objective psychology.

But in the problem of the child's cultural development the ways of objective and subjective psychology diverge as they approach the higher mental functions. Whereas objective psychology consistently altogether refuses to discriminate between the higher and lower mental functions, limiting itself to dividing reactions into inborn and acquired and regarding all acquired reactions as a single class of skills, empiric psychology, on the one hand, limited with magnificent consistence the child's development to maturation of elementary functions and, on the other hand, built over each elementary function a second storey taking it from no one knows where.

In addition to mechanical memory, logical memory was distinguished as its highest form; voluntary attention was superimposed on involuntary attention; reproductive imagination was topped by creative imagination; conceptual thinking rose as a second storey over imaginative thinking; lower feelings were symmetrically supplemented by higher feelings, and impulsive volition—by previsional volition.

Thus the whole theory of the most important mental functions was built in two storeys. But since child psychology had to do only with the lower storey, while the development and origin of the higher functions remained entirely unelucidated, this created a gap between child psychology and general psychology. What general psychology found and set apart as voluntary attention, creative imagination, logical memory, previsional volition, etc., i.e., the higher forms, the higher functions, remained *terra incognita* for child psychology.

Failure to ascertain the genesis of the higher functions

inevitably leads to an essentially metaphysical conception, namely, the higher and lower forms of memory, attention and thinking exist side by side, independent of each other, unconnected genetically, functionally or structurally, as though originally created separately, as the existence of various species of animals was conceived before Darwin. This closed the way to scientific investigation and explanation of the higher processes also for general psychology, so that not only the history of development, but also the theory of logical memory and voluntary attention is absent from modern psychology.

This metaphysical division of psychology into two storeys, this dualism of the higher and the lower finds its extreme expression in the idea of dividing psychology into two separate and independent sciences: physiologic, natural-science, explanatory or causal psychology, on the one hand, and conceptual, descriptive or teleological psychology of the spirit, as the basis of all the humanities, on the other hand. This idea of Dilthey, Münsterberg, Husserl and many others, extraordinarily popular in our time and numbering many adherents, reveals in pure form two heterogeneous and in a certain sense contrary tendencies which have opposed each other within empirical psychology as long as it has existed.

It is impossible to find more convincing proof of the insolubility of the problem of higher mental functions on the basis of empirical psychology than the historical fate of this science, breaking up in two before our very eyes and striving to sacrifice its lower part to natural science in order to retain the higher part in pure form and thereby rendering unto Caesar what is Caesar's.... Thus the dilemma which empirical psychology has realised as fatal and inevitable consists in the choice of either physiology of the mind or metaphysics. Psychology as a science is impossible—such is the historical result of empirical psychology.

We have endeavoured to show the present-day state of the problem of development of the higher mental functions and the blind alleys into which the problem has been driven in the most important psychological systems of our time so that we may thereby, first, outline the concrete content and subject of our investigation and disclose the

content of the concept of "development of the higher mental functions" or "the child's cultural development", secondly, state the problem of development of the higher mental functions as one of the main problems of child psychology, and, thirdly, outline the methodological conception of this most complicated and extraordinarily muddled problem, and seek an approach to it.

The concept of "development of the higher mental functions" covers two groups of phenomena which at first sight appear entirely dissimilar, but are actually two main branches, two inseparably connected but never confluent streams of development of the higher forms of behaviour. These are, first, the processes of mastering the external means of cultural development and thinking—language, writing, counting and drawing, and, secondly, the processes of development of the special higher mental functions which are not delimited, nor in any way exactly defined, and are called in traditional psychology voluntary attention, logical memory, formation of concepts, etc. All of them taken together form what we conventionally call the process of development of the higher forms of the child's behaviour.

In this conception the problem of development of the higher forms of behaviour has never occurred to child psychology as a special problem. It is not found in the modern system of child psychology as a single and special field of investigation and study. It is dispersed in parts through most diverse chapters of child psychology. Nor could either of the two main parts of our problem—development of the child's speech, writing and drawing, and development of the higher mental functions in the proper sense of the word, as we have already seen, be adequately solved separately in child psychology.

This is due mainly to the fact that child psychology has not yet learned the indubitable truth that it is necessary to distinguish two, essentially different lines in the child's mental development. In dealing with the development of the child's behaviour child psychology does not know which of the two lines it is a question of, confuses the two lines and regards this confusion—the product of an undifferentiated scientific conception of a complex process—as the real unity and simplicity of the process itself. In a word, child psychology continues to regard the process of

development of the child's behaviour as simple, whereas it is actually a complex process. This is undoubtedly the source of all the main fallacies, false interpretations and erroneous statements of the problem of "development of the higher mental functions". Ascertainment of this proposition about the two lines of the child's mental development forms a necessary prerequisite for all of our investigation.

The behaviour of a modern cultured adult is the result of two different processes of mental development: the process of biological evolution of the animal species which gave rise to the species of *homo sapiens*, and the process of historical development which has transformed primitive man into cultured man. Both these processes of biological and cultural development of behaviour are represented in the phylogenesis separately as individual and independent lines of development, constituting the object of various independent psychological disciplines.

The specificity and difficulty of the problem of development of the child's higher mental functions are that in the ontogenesis both these lines blend and actually form a single, although complex process. That is precisely why child psychology has not yet become aware of the specificity of the higher forms of behaviour, whereas ethnic psychology (psychology of primitive peoples) and comparative psychology (biological, evolutionary psychology) which deal with one of the two lines of phylogenetic development of behaviour have long since become aware each of its own subject. It will never occur to the representatives of these sciences to identify these two processes and to consider the development from primitive man to cultured man a mere continuation of the development from animal to man or to reduce the cultural development of behaviour to biological development. And yet this is precisely what is taking place at each step in child psychology.

We must therefore turn to the phylogenesis which does not know of any unification and blending of the two lines in order to undo the knot which has formed in child psychology.

The radical and fundamental difference between man's historical development and the biological evolution of the animal species is known well enough; that is why, to the extent that man's historical development differs from the

biological evolution of the animal species, the cultural type of development of the behaviour must apparently differ from the biological type of development, since the two processes form part of more general processes—history and evolution.

Thus we are faced with the process of psychological development *sui generis*, a process of its own kind.

The fact that the development of the higher mental functions takes place without any changes in the biological type of man, whereas the change in the biological type is the basis of the evolutionary type of development, must be considered the basic and decisive difference between this process and the evolutionary process. It is well known and has been repeatedly pointed out that this feature also forms the general difference from man's historical development. With the entirely changed type of adaptation it is the development of man's artificial organs—tools—and not the change in organs and body structure that comes to the foreground.

Primitive man does not display any essential differences in the biological type, differences which may account for the enormous difference in behaviour. All the latest investigations in this field agree that this equally applies to the most primitive man of the now living tribes, who, according to the expression of one of the investigators, must be awarded the full title of man, and to prehistoric man of the closest epoch, who, as we know, also does not display such appreciable somatic differences which may warrant regarding him as a lower category of man. In both cases, according to the same investigator, we are dealing with a full-fledged, only more primitive, human type.

All investigations confirm this proposition and show that there are no essential differences in the biological type of primitive man, which might account for the behaviour differences between primitive and cultured man. None of the elementary psychological and physiological functions—perceptions, movements, reactions, etc.—show any deviations from the same functions of cultured man. This is as basic a fact for the psychology of primitive man, for historical psychology, as the contrary proposition is for biological psychology.

But to the same extent that the elementary psychophysiological functions have remained unchanged in the proc-

ess of historical development, the higher functions (verbal thinking, logical memory, formation of concepts, voluntary attention, volition, etc.) have suffered deep and all-round changes.

Culture creates special forms of behaviour, modifies the activity of the mental functions and adds new storeys to the developing system of human behaviour. This is the basic fact of which we are persuaded by every page of psychology of primitive man, which studies cultural-psychological development in its pure, isolated form. In the process of historical development social man changes the ways and means of his behaviour, transforms the natural instincts and functions, elaborates and creates new forms of behaviour—specifically cultured forms.

Child psychology did not know of the problem of higher mental functions or, what is the same thing, the problem of the child's cultural development. That is why the central and highest problem of psychology—the problem of the personality and its development—is still closed to it. Through its best representatives child psychology arrives at the conclusion that the "description of the inner life of man as a whole is the province of a poet or a historian". Essentially this is a *testimonium paupertatis*, i.e., a statement of failure of child psychology, an admission that it is absolutely impossible to investigate the problem of personality within the methodological boundaries within which child psychology has arisen and developed. Only by decisively going beyond the methodological limits of traditional child psychology may it be possible to investigate the development of the higher mental synthesis which must with good reason be called the child's personality. The history of the child's cultural development brings us to the history of the development of the personality.

METHOD OF INVESTIGATION

Investigation of any new sphere necessarily begins with a search for and elaboration of a method. It may be suggested, as a general proposition, that any new approach to scientific problems inevitably leads to new methods and ways of investigation. The object and method of investigation prove to be closely interconnected. The investigation therefore assumes an entirely different form and takes a

different course when it is aimed at finding a new method which is adequate to the new problem; in this case the form of the investigation radically differs from the forms in which the study merely uses in new spheres the methods already elaborated and established in science.

All the psychological methods now used in experimental investigation are, despite their enormous diversity, built on one principle, according to one type, one scheme, namely, stimulus-response. However original and complex the type of psychological experiment, it is always easy to see that it stands on this universal foundation. Whatever the object and method of the psychologist's experiment, it is always a question of exerting some action on the person, exposing him to particular stimuli, in some manner stimulating his behaviour or experiences, and then studying, investigating, analysing, describing and comparing the response to this action, the reaction to the given stimulus.

This method of investigation undoubtedly rests on the basic proposition, the basic psychologic law, according to which mental processes are reactions to stimuli. The basic scheme of the experiment—stimulus-response—is at the same time the basic law of behaviour. All sorts of connections, depending on the constellation and change in the stimuli and reactions have been investigated in psychology, but we do not know of a single investigation with a fundamental step made beyond the basic, essentially elementary law of behaviour. All changes were wrought within the general scheme. Even the method of conditioned reflexes finds its place within the same general range. So different from other methods in all other respects, in this respect it hinges on their common pivot.

This scheme underlies the psychological experiment however diverse the forms it assumes in investigations of various trends and whatever fields of psychology it penetrates. This scheme embraces all trends—from associationism to structural psychology, all fields of investigation—from elementary to higher processes, all branches of psychology—from general to child psychology.

However, this proposition has its reverse side which is that with the generalisation and spread of our scheme to more extensive spheres of psychology the concrete content of this scheme has evaporated and disappeared in direct proportion to these processes. It may screen the most

diverse and exactly opposite approaches to the human mind and behaviour, the most diverse aims and objectives of investigation, and, lastly, the most different fields of investigation. The following question arises: under the circumstances isn't the entire scheme an empty, meaningless form which is generally devoid of any content, and isn't our generalisation therefore devoid of any meaning?

The common elements that unite all types and forms of psychological experiment and that are in various measure characteristic of all of them, since they rest on the S-R principle, constitute a naturalistic approach to human psychology, which must be disclosed and overcome if we are to find an adequate method of investigating the cultural development of behaviour. In its essence this view seems to us to be related to the naturalistic conception of history, the one-sidedness of which consists, according to F. Engels, in that it holds that "nature exclusively reacts on man, and natural conditions everywhere exclusively determine his historical development", and forgets that "man also reacts on nature, changing it and creating new conditions of existence for himself".*

The naturalistic approach to behaviour as a whole, including the higher mental functions which have formed during the historical period of development of behaviour, does not take into consideration the qualitative difference between the history of man and the evolution of animals. The S-R scheme is essentially used in the same manner in investigating the behaviour of man and the behaviour of animals. This fact alone expresses the idea that all the qualitative differences in the history of man, all the "changes in human nature", the whole new type of human adaptation—all of it has failed to affect human behaviour and to cause any fundamental changes in it. This idea actually declares that human behaviour is outside the pale of the general historical development of man.

However ungrounded and even preposterous as this idea, when openly stated, may be, when concealed it continues to be a silent prerequisite, an unuttered principle of experimental psychology. It is unthinkable that labour, which has radically changed the character of man's adap-

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* F. Engels, *Dialectics of Nature*, Progress Publishers, Moscow, 1964, p. 234.

tation to nature, is unconnected with the change in the type of man, if we assume together with Engels that "a tool implies specific human reality, the transforming reaction of man on nature, production".* Is it possible that in the psychology of man nothing corresponds to the difference in the relation to nature, which sets man apart from animals and which Engels implies when he says that "the animal merely *uses* his environment, man by his changes makes it serve his ends", or in other words, that "all the planned action of all animals has never succeeded in impressing the stamp of their will upon the earth. That was left for man".**

The S-R scheme and the naturalistic approach to human psychology it screens assume human behaviour to be essentially passive.

If we take into account these purely theoretical considerations and add the actual impotence of experimental psychology in applying the S-R scheme to investigation of the higher mental functions, we will see that this scheme cannot serve as the basis for constructing an adequate method of investigating specifically human forms of behaviour. At best it will help us to discern the presence of lower, subordinate "collateral forms" which "do not exhaust the essence of the main form". Application of this universal, all-embracing scheme to all stages of development of behaviour may but lead to establishment of a purely quantitative variety, complication and enhancement of human stimuli and reactions, compared with those of animals, but cannot grasp the new quality in human behaviour, because the development of behaviour from animals to man gave rise to a new quality, and this is our main idea. This development does not exhaust by a simple complication the relations between the stimuli and responses which are already given to us in the psychology of animals. Nor does it proceed along the path of quantitative increase and extension of these connections. It is centred upon a dialectical leap which leads to a qualitative change in the very relation between the stimulus and the response. Human behaviour—we could thus formulate our

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* F. Engels, *Dialectics of Nature*, Progress Publishers, Moscow, 1964, p. 34.

** Ibid., p. 182.

main conclusion—differs from the behaviour of animals in the same qualitative manner as the entire type of adaptation and historical development of man differs from the adaptation and development of animals, because the process of man's mental development is part of the general process of man's historical development. We are thereby compelled to seek and find a new methodological formula for psychological experiment.

We started our investigation with a psychological analysis of several forms of behaviour which are encountered, not often, to be sure, in day-to-day life and are therefore familiar to everybody, but are at the same time an extremely complex historical formation of the most ancient epochs in man's psychological development.

These negligible and at the same time deeply significant phenomena may be with good reason called rudimentary mental functions by analogy with the rudimentary organs.

The rudimentary functions which we find in any system of behaviour and which are vestiges of similar, but more developed functions in other, older psychological systems are a living evidence of the origin of these higher systems in their historical connection with older strata in the development of behaviour. That is why their study may reveal essential data for understanding human behaviour, the data which we need to find the basic formula for the method. And that is why we decided to begin with small and negligible facts and to raise their investigation to a high theoretical level in an attempt to show how the great manifests itself in the very small.

An analysis of these psychological forms reveals to us what were formerly the higher mental functions included with them in one system of behaviour and what was this very system in which rudimentary and active functions coexist. This analysis furnishes us with the point of departure of their genesis and at the same time the point of departure of the entire method.

As ancient formations which arose in the very beginning of cultural development they have retained in pure form the principle of their structure and activity, the prototype of all other cultural forms of behaviour. What exists in infinitely more complex processes in concealed form is here open to view. All the connections with the system which at one time gave rise to them have died

away, the ground on which they arose has disappeared, the background of their activity has changed, they were severed from their system and were transported by the stream of historical development to an entirely different sphere. They are bearers of their own history. To analyse each such form, requires a small and finished separate monograph the size of a page. But, unlike the a priori constructions and artificially created examples and schemes, they are real formations, finding their direct and immediate continuation in experiment which reproduces their basic forms and, in investigation of primitive man, reveals their history.

The first form of behaviour in which we are interested may be very easily pictured in connection with the specific situation in which it usually arises. This situation, in its extreme and simplified expression, is usually referred to as the situation of Buridan's ass on the basis of the well-known philosophical joke figuring in the writings of the most diverse thinkers; the joke is ascribed to Buridan in whose writings, incidentally, it does not appear at all. A hungry ass standing at an equal distance from two absolutely similar bundles of hay suspended on the right and left sides must starve to death because the motives prompting him are equally powerful and are aimed in opposite directions. This famous joke is supposed to illustrate the idea of absolute determination of behaviour, the idea that the will is not free. What would man do in a similar ideal situation?

Some thinkers asserted that man would suffer the sad fate of the ass. Others, on the contrary, held that man would be a most shameful ass and not a thinking creature—*res cogitans*—if he perished under the same circumstances.

Essentially, this is the basic problem of all of human psychology. It presents in an extremely simplified, ideal form the entire problem of our investigation, the entire stimulus-response problem. If two stimuli act with equal force in opposite directions, simultaneously evoking two incompatible reactions, complete inhibition results with mechanical necessity, behaviour is arrested and there is no way out.

A person finding himself in the situation of Buridan's ass resorts to the aid of *auxiliary motives or stimuli artificially introduced into the situation*. In place of Buri-

dan's ass man would throw lots and thus master the situation.

In the behaviour of people who have grown up under conditions of a backward culture casting lots plays an enormous role. According to investigators, in difficult cases many primitive tribes never take an important decision without casting lots. Bones thrown and fallen in a definite manner serve as the decisive auxiliary stimulus in the struggle of motives. Lévy-Bruhl describes numerous methods by which an alternative is chosen with the aid of artificial stimuli entirely unrelated to the situation and introduced by primitive man exclusively as an aid to choosing one of two possible reactions.

If we isolate in pure form the very principle of constructing the operation of casting lots, we shall easily see that its most important feature consists in the new and entirely unusual relation between the stimuli and responses which are impossible in the behaviour of an animal.

Let us take a situation in which man is acted upon by two equally powerful and opposite stimuli *A* and *B*. If the joint action of the two stimuli leads to a mechanical addition of these actions, i.e., to a complete absence of any reactions, we have what should have happened, according to the joke, to Buridan's ass. This is the highest and purest expression of the stimulus-response principle in behaviour. Complete determinability of behaviour by stimulation and complete possibility of studying the whole of the behaviour by the S-R scheme are shown here in the most simplified ideal form.

In the same situation man throws lots. He introduces artificially into the situation, without changing it, without in any way connecting with it, auxiliary stimuli *a-A* and *b-B*. If stimulus *a* drops out, he will follow stimulus *A*, if stimulus *b* falls out, he will follow stimulus *B*. He creates his own artificial situation by introducing a couple of auxiliary stimuli. He determines his behaviour beforehand, making his choice with the aid of a stimulus introduced by himself. Let us assume that in casting lots stimulus *a* drops out. Stimulus *A* thereby wins. This stimulus *A* evokes the corresponding reaction *X*. Stimulus *B* evokes no reaction. Its corresponding reaction *Y* could not be produced.

Let us analyse what has taken place. Reaction *X* was, of course, evoked by stimulus *A*. Without this stimulus the

reaction could not have occurred. But X was evoked not only by A. A itself was neutralised by the action of B. Reaction X was evoked also by stimulus a which has nothing to do with it and was introduced into the situation artificially. Thus the stimulus created by man himself determined his reaction. We may, consequently, say that *man determined his own reaction with the aid of an artificial stimulus.*

Like the casting of lots, *tying a knot* to remember something belongs to psychology of everyday life. Man wants to remember something; for example, he must execute some commission, do something, take something, etc. Not trusting his memory and not relying on it he usually ties a knot on his handkerchief or in an analogous manner places a piece of paper under the lid of his pocket watch, etc. The knot must remind him later of what he has to do. And, as everybody knows, in some cases it may serve as a reliable aid to memory.

Here is another operation which is unthinkable and impossible in an animal. We are again ready to see a new, specifically human behaviour characteristic in the introduction of an artificial auxiliary memory aid, in the active creation and use of a stimulus as a memory aid.

But the essence of the form of behaviour in which we are interested remains the same in all cases. This essence is in the transition from the direct perception of quantity and immediate reaction to a quantitative stimulus to the creation of auxiliary stimuli and active determination of one's own behaviour with their aid. Artificial stimuli created by man, in no way connected with the situation on hand and placed in the service of active adaptation, again appear as a distinguishing feature of higher forms of behaviour.

With this we may finish analysing concrete examples. Further consideration would inevitably make us repeat in new forms and manifestations the main feature, which we have singled out. We are interested in that extremely peculiar world of higher or cultured forms of behaviour which opens up beyond them and which investigation of inactive functions helps us to penetrate. We are searching for the key to higher behaviour.

It occurs to us that we have found it in the principle of constructing the psychological forms which we have analysed. It is in this that the heuristic significance of

investigating rudimentary functions consists. As we have already mentioned, these psychological fossils, these living vestiges of ancient epochs clearly show the structure of the higher form. These rudimentary functions reveal to us what all higher mental processes were like before and to what type of organisation they at one time belonged.

In all the cases we have examined, man's behaviour was determined not by the stimuli on hand, but by a new or invariably man-made psychological situation. Creation and use of artificial stimuli as aids to mastery of one's own reactions are the basis of the determinability of behaviour which distinguishes higher behaviour from elementary. The presence of *created* stimuli in addition to *given* stimuli is in our opinion a distinguishing feature of human psychology.

These artificial stimuli—means introduced by man into a psychological situation and performing the function of autostimulation—we call *signs,* attaching to this term a broader and at the same time more exact meaning than the usual meaning. According to our definition, any conditioned stimulus artificially created by man and serving as a means of mastering behaviour—one's own or someone else's—is a sign. Two factors are thus essential for the concept of sign: its origin and function.

The behaviour of man is distinguished by the fact that he creates artificial signalling stimuli, primarily a grand signal system of speech, and thereby masters the signalling activity of the cerebral hemispheres. Whereas the basic and most common activity of the cerebral hemispheres of animals and man is signalling, the basic and most common activity of man, which primarily distinguishes man from animals psychologically, is *signification*, i.e., creation and use of signs. We are taking this word in its literal and precise sense. Signification is creation and use of signs, i.e., artificial signals.

It is quite clear that such signalling which is a reflection of the natural connections of phenomena and is entirely a creation of natural conditions cannot form an adequate basis for human behaviour. Active *reshaping of nature by man* is essential to human adaptation. This reshaping of nature by man underlies all of human history. It necessarily presupposes an active change in human behaviour. "By thus acting on the external world and changing it,

he at the same time changes his own nature," says K. Marx. "He develops his slumbering powers and compels them to act in obedience to his sway."*

Every definite stage in mastering the forces of nature necessarily corresponds to a definite stage in the mastery of behaviour, in subordinating the psychological processes to the power of man. Active adaptation of man to the environment and the change in man's nature cannot be based on signalling which passively reflects the natural connections of various agents. They require an active coupling of such connections which are impossible in a purely natural type of behaviour, i.e., based on a natural combination of the agents. Man introduces artificial stimuli, signifies behaviour and by means of signs creates from without new connections in the brain. Together with the assumption of this we tentatively introduce a new regulatory principle of behaviour into our investigation, a new conception of determinability of man's reactions. It is the principle of signification which means that man creates from without connections in his brain, controls his brain and through it his own body.

A question naturally arises: how is it generally possible to create connections from without and regulate the behaviour of the type under discussion? This possibility is offered in the coincidence of two factors. In point of fact, the possibility of such regulatory principle lies as an inference in the prerequisite, in the structure of the conditioned reflex.

The theory of conditioned reflexes is based on the idea that the main difference between a conditioned and an unconditioned reflex is not their mechanism, but the formation of the reflex mechanism. "The only difference is," says I. P. Pavlov, "that in one case there is a ready-made conduction path, whereas the other case requires preliminary coupling; in one case the mechanism of communication is quite ready, in the other case the mechanism is somewhat supplemented each time until it is completely ready."** Consequently, the conditioned reflex is a mechanism newly

* K. Marx, *Capital,* Vol. I, Foreign Languages Publishing House, Moscow, 1958, p. 177.

** I. P. Pavlov, *Complete Works,* Vol. IV, Moscow-Leningrad, Publishing House of the U.S.S.R. Academy of Sciences, 1951, p. 38.

created by a coincidence of two stimuli, i.e., created from without.

The second factor, whose presence explains the possibility for the appearance of a new regulatory principle of behaviour, is the social life and interaction of people. In the process of social life man has created and developed most complex systems of psychological connections without which neither work nor all of the social life would be possible. These means of psychological connections are in their very nature and function signs, i.e., artificially created stimuli whose purpose is to stimulate behaviour, to form new reflex connections in the human brain.

The two factors taken together enable us to understand the possibility of formation of the new regulatory principle. Social life makes it necessary to subordinate the behaviour of the individual to social requirements and at the same time creates complex signal systems—means of communication which direct and regulate the formation of conditioned connections in the brain of man. The organisation of higher nervous activity creates the necessary prerequisite for it, creates the possibility of regulating behaviour from without.

In explaining man's behaviour from the psychological aspect the inadequacy of the regulatory principle consisting in construction of the conditioned reflex is, as was already mentioned, that by means of this mechanism we can only understand how the natural inborn connections regulate the formation of connections in the brain and human behaviour, i.e., understand behaviour on a purely naturalistic, but not historical plane. This regulatory principle quite corresponds to the passive type of animal adaptation.

But no natural connections make it possible to understand the active adaptation to nature, the change of nature by man. This can be understood only from man's social nature. Otherwise we return to the naturalist assertion that only nature acts on man. "Natural science, like philosophy," says Engels, "has hitherto entirely neglected the influence of men's activity on their thought; both know only nature on the one hand and thought on the other. But it is precisely *the alteration of nature by men,* not solely nature as such, which is the most essential and immediate basis of human thought, and it is in the measure

that man has learned to change nature that his intelligence has increased."*

This new type of behaviour must necessarily correspond to a new regulatory principle of behaviour. We find it in the social determination of behaviour realised by means of signs. The leading role in all social connections is played by speech. I. P. Pavlov says that "owing to all of an adult's preceding life the word is connected with all the external and internal stimuli reaching the cerebral hemispheres, it signals them all, replaces all of them and may therefore evoke all the actions and reactions of the organism conditioned by these stimuli".**

Man's psychological development took place in the phylogenesis and is taking place in the ontogenesis not only along the line of improving and complicating the grandest signal panel, i.e., the structure and function of the neural apparatus, but also along the line of elaborating and acquiring a correspondingly grand system of speech signals which are the key to this panel.

So far our discourse appears perfectly clear. There is an apparatus meant for the coupling of temporary connections and there is a key to this apparatus, which makes it possible, in addition to the connections forming by themselves under the influence of natural agents, to produce new, artificial couplings subject to man's will and choice. The apparatus and key to it are in different hands. One man influences another through speech. But the complexity of the problem becomes obvious as soon as we connect the apparatus and the key in one person, as soon as we begin to deal with the concept of autostimulation and self-mastery. Here psychological connections of a new type arise within the selfsame system of behaviour.

We shall place this transition from the social influence outside the personality to the social influence within the personality in the centre of our investigation and shall attempt to elucidate the most important factors from which the process of such transition forms.

The use of auxiliary means, the transition to mediating activity radically reorganises the entire mental operation,

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* F. Engels, *Dialectics of Nature*, Progress Publishers, 1964, p. 234.

** I. P. Pavlov, *Complete Works*, Vol. IV, Moscow-Leningrad. Publishing House of the U.S.S.R. Academy of Sciences, 1951, p. 429.

as the use of a tool modifies the natural activity of organs and endlessly extends the system of activity of the mental functions. The former and the latter together we designate by the term of *higher mental function* or *higher behaviour.*

STRUCTURE OF THE HIGHER MENTAL FUNCTIONS

The conception of psychological analysis which we have endeavoured to develop brings us to a new idea of the mental process, as a whole, and of its nature. The most important change that has of late occurred in psychology is the replacement of the analytical approach to the mental process by the integral or structural approach. The most influential representatives of modern psychology advance the integral point of view and assume it as the basis of all of psychology. The essence of this new point of view is that it pushes to the foreground the importance of the whole which possesses its own specific properties and determines the properties and functions of its constituent parts. Unlike old psychology which conceived the process of formation of complex forms of behaviour as a process of mechanical summation of separate elements, new psychology centres the study on the whole and on such of its properties which cannot be inferred from the sum of the parts.

In the history of the child's cultural development we meet with the concept of structure twice. First, this concept arises in the very beginning of the history of the child's cultural development, forming the initial factor or point of departure of the entire process; secondly, the very process of cultural development must be conceived as a change in this initial, basic structure and a rise, on its basis, of new structures characterised by a new correlation of the parts. The former structures we shall call primitive; they are the natural, inborn psychological whole conditioned mainly by biological characteristics of the mind. The latter structures arising in the process of cultural development we shall call the higher structures because they represent a genetically more complex and higher form of behaviour.

The new structures which we oppose to the lower or primitive structures differ primarily in that the direct confluence of the stimuli and reactions in a single complex is in this case disturbed. If we analyse the peculiar forms

of behaviour, which we have an opportunity to observe in the reaction of choice, we cannot but notice that here the primitive structure undergoes, as it were, a stratification in behaviour. A new intermediate link appears between the stimulus at which the behaviour is aimed and man's reaction to it, and the entire operation assumes the character of a mediated act. In this connection this analysis suggests a new point of view concerning the relations existing between the act of behaviour and the external phenomenon. We can clearly distinguish two series of stimuli of which some are object stimuli and others are means stimuli; each of these stimuli peculiarly, according to its correlations, determines and directs behaviour. The specific feature of the new structure is the presence in it of stimuli of both orders. In our experiments we were able to observe how the very structure of the entire process changed, depending on the change in the place of the middle stimulus (sign) in behaviour. It was enough to use words as means of memorisation* to impart one direction to all these processes associated with memorising instructions. But as soon as these words were replaced by meaningless figures the entire process assumed a different direction. Owing to these very simple experiments we deem it possible to suggest, as a general rule, the following proposition: *in the higher structure the sign and the method of its use are the functional, determining whole or focus of the entire process*. Just as the use of a tool dictates the entire structure of a labour operation, the character of the sign used is the basic factor which underlies the construction of the whole remaining process. Thus, the most important factor underlying the higher structure is a special form of organisation of the whole process consisting in the fact that the whole process is constructed by drawing into situation well-known artificial stimuli which play the part of signs. Consequently, the functionally

* Here L. S. Vygotsky describes the experiment, suggested by him, with mediated memorisation in which a series of words is memorised with the aid of a series of additional auxiliary signals (pictures or words); by using these aids the subject is able essentially to extend the limits of his memory. This method is specially described in the following books by A. N. Leontyev: *Development of Memory*, published by the Academy of Communist Education in 1931, and *Problems of Development of the Mind*, published by the Academy of Pedagogical Sciences in 1959, Moscow. (*Editor's note*.)

different role of two stimuli and their interconnections underlie the connections and relations which form the very process.

The process of drawing extraneous stimuli into the situation which in this case assumes a certain functional importance may best be observed in experiments in which the child for the first time passes from the direct operation to using signs. In our experimental studies we placed the child in a situation in which he was faced with a problem of memorising, comparing or choosing something. If this problem was not beyond the child's natural abilities, the child managed to cope with it by a direct or primitive method. An essential feature of this scheme is that the reaction itself forms part of the situation and is necessarily included in the structure of this situation as a whole. That dominating whole, mentioned in its time by Volkelt, predetermines already the direction of the child's grasping movement. But in our experiment the situation is hardly ever such. The problem with which the child is faced is, as a rule, beyond his ability and is usually insoluble by such a primitive method. But, if some material altogether neutral with respect to the entire situation lies before the child, we happen to observe, under certain conditions, how these neutral stimuli cease to be neutral when the child is faced with an insoluble problem and how they are drawn into the process of behaviour and assume the function of a sign.

In application to the structure we could say that precisely the differentiation of the primitive wholeness and the clear singling out of two poles (sign stimulus and object stimulus) are the characteristic feature of the higher structure, but this differentiation has its other aspect which consists in the fact that the entire operation as a whole assumes a new character and significance. We could not describe this new significance of the whole operation otherwise than by saying that it is *mastery of one's own process of behaviour*. It is surprising to us that traditional psychology completely failed to notice this phenomenon which we can call mastering one's own reactions. In the attempts to explain this fact of "will" this psychology resorted to a miracle, to intervention of a spiritual factor in the operation of nervous processes, and thus tried to explain the action by the line of most resistance, as did,

for example, James in developing his theory of the creative character of the will.

But even recent psychology which is gradually introducing the concept of mastery of one's own behaviour into the system of psychologic concepts does not as yet have the necessary clarity in this very concept or an adequate evaluation of its true significance. K. Lewin notes with good reason that phenomena of mastering one's own will have not yet appeared with complete clarity in the psychology of the will. Contrariwise, in pedagogics the problems of mastering one's own behaviour have long since been considered the basic problems of education. In modern education the will has replaced the proposition of purposive action. External discipline, compulsory drill is replaced by independent mastery of one's own behaviour, which presupposes no suppression of the child's natural inclinations, but implies the child's mastery of his own actions. In connection with this, obedience and good behaviour are pushed into the background and the problem of self-mastery is brought to the foreground. And this problem is really of much greater importance since we mean the purpose which governs the child's behaviour. This recession of the problem of purpose into the background with respect to the problem of self-mastery is manifested in the problem of a small child's obedience. A child must learn to obey through self-mastery. Self-mastery is not built on obedience and purpose, but, on the contrary, obedience and purposiveness arise on self-mastery. The analogous changes with which we are familiar from the pedagogics of the will are necessary for the main problem of psychology of the will.

We are summing up our basic views.

As was already mentioned above, we proceed from the proposition that the processes of behaviour are the same natural processes governed by natural laws as all the others. Subordinating the processes of nature to his power and intervening in the course of these processes man makes no exception for his own behaviour either. However, the main and most important question arises as to how we must conceive this mastery of one's own behaviour.

Old psychology knew two basic facts. On the one hand, it knew the fact of the hierarchic relations between the higher and lower centres owing to which some processes

regulate the course of others; on the other hand, by resorting to the spiritualistic interpretation of the problem of the will, it suggested the idea that the psychologic forces act on the brain and through it on the whole body.

The structure which we imply differs essentially from both the former and latter cases. The difference is in the fact that we emphasise the problem of the means by which the behaviour is mastered. Like mastering any natural processes, the mastery of one's own behaviour presupposes not abrogation of the main laws which govern these phenomena, but obedience to them. But we know that the main law of behaviour is the stimulus-response law, for which reason we cannot master our own behaviour other than through corresponding stimulation. Mastery of the stimuli offers the key to mastering the behaviour. Thus, *mastering the behaviour is a mediated process which is always carried into effect through certain auxiliary stimuli.*

We might sum up that to which we are brought by the comparative consideration of the higher and lower forms of behaviour and say that the unity of all the processes, which are constituents of the higher form, is based on two factors: first, the unity of the problem with which man is faced and, secondly, the means, which, as was already said, dictate their structure of the process of behaviour.

GENESIS OF THE HIGHER MENTAL FUNCTIONS

The analysis and structure of the higher mental processes bring us close to elucidating the basic problem of the entire history of the child's cultural development, elucidating the genesis of the higher forms of behaviour, i.e., the origin and development of the mental forms which constitute the subject of our study.

If we examine the concept of development, as it appears in modern psychology, we shall see that it still contains many factors which modern investigations must overcome.

The first of these factors, the sad survival of prescientific thinking in psychology, is the latent, vestigial preformism in the theory of child development. Old conceptions and erroneous theories disappear from science, leaving traces, vestiges in the form of habits of thought. Despite the fact that the science about the child has long since rid itself of the view that the child differs from an adult only in

bodily proportions, only in size, this conception has been retained by child psychology in a concealed form. Not a single work in child psychology can now openly repeat the long disproved ideas that the child is an adult in miniature, and yet this view persists and can still be found in concealed form in almost every psychological investigation.

From the point of view of child psychology the entire process of development can be conceived extraordinarily simply; it consists in a quantitative increase in size of that which is given from the very outset in the embryo, the embryo gradually enlarging, growing and thus developing into a mature organism. This point of view has long since been discarded by embryology and is only of historical interest. And yet, in psychology this point of view continues to exist in practice, although it has also long since been abandoned in theory.

Theoretically psychology long ago gave up the idea that the child's development is a purely quantitative process. Everybody agrees that we are dealing with a much more complex process which is not exhausted by quantitative changes alone. But in practice psychology has yet to disclose this complex process of development in all its completeness and grasp all the qualitative changes and transformations which reshape the child's behaviour in the process of development.

If we were to characterise by one general proposition the basic demand made of modern investigation by the problem of development, we could say that it consists in studying the positive peculiarity of the child's behaviour.

Psychology is now faced with the problem of grasping this real peculiarity of the child's behaviour in all the completeness and wealth of its actual expression, and of producing a positive picture of the child's personality. But this positive picture becomes possible only if we radically change our conception of the child's development and if we take into account that it is a complex dialectical process which is characterised by complex periodicity, disproportion in the development of various functions, metamorphoses or qualitative transformations of some forms into others, complex interlacement of processes of evolution and involution, complex crossing of external and internal factors, and a complex process of surmounting difficulties and of adaptation.

Another factor, the surmounting of which must clear the way to modern genetic investigation, is the concealed evolutionism which still dominates child psychology. Evolution, or development by means of gradual and slow accumulation of various changes, continues to be regarded as the only form of the child's development which exhausts all the known processes forming part of this general conception. Essentially the discourses on child development contain a concealed analogy with the process of plant growth.

Child psychology will have nothing to do with those sudden, leaplike revolutionary changes with which the history of child development is replete and which are so often encountered in the history of cultural development. To naive consciousness evolution and revolution seem incompatible. For it historical development continues only as long as it proceeds along a straight line. Where there is a revolution, a disruption of historical tissue, a leap, naive consciousness sees only catastrophe, downfall and a precipice. There history ends for it for the entire period until it takes the straight and even road again.

Scientific consciousness, on the contrary, regards revolution and evolution as two interconnected and mutually-supposing forms of development. The leap performed in the development of the child at the moment of such changes scientific consciousness regards as a point in any line of development as a whole.

This proposition is of particular importance to the history of cultural development since, as we shall see below, the history of cultural development occurs to an enormous extent through such sudden, leaplike changes taking place in the child's development. The very essence of cultural development consists in the clash between the developed cultural forms of behaviour, which the child encounters, and the primitive forms which characterise his own behaviour.

The immediate conclusion from this is a change in the usual point of view concerning the processes of the child's mental development and a change in the conception of the character of construction and course of these processes. All processes of child development are usually conceived as stereotypical processes. In this sense the sample of development, its model, as it were, with which all the other

forms are compared is embryonal development. This type of development depends the least on the external environment and to it may with good reason be applied the term "development" in its literal sense, i.e., unfolding in the embryo in a limited form of possibilities. And yet, embryonal development cannot be considered the model for any and all processes of development in the strict sense of the word. It may rather be conceived as its result or consequence. It is already a stabilised, completed and more or less stereotypical process.

Suffice it to compare with this process of embryonal development the process of evolution of the animal species, the real origin of the species, as it was disclosed by Darwin, to see that there is a fundamental difference between the former and the latter types of development. Species came into being and perished, were modified and developed in the struggle for existence, in the process of adaptation to their surroundings. If we were to draw an analogy between the process of child development and some other process of development, we should rather choose evolution of the animal species than embryonal development. Child development least of all resembles a stereotypical process screened from external influences; here the development of and changes in the child take place in an active adaptation to the external environment.

Ever new forms arise in this process, and it is not merely links of an already formed chain which are stereotypically reproduced. Any new stage in the development of the embryo, contained already in a potential form in the preceding stage, occurs by virtue of the unfolding of these internal potentials; it is not so much a process of development as a process of growth and maturation. This form, this type, is also represented in the child's mental development; but in the history of cultural development a much more important part is played by the second form, the second type, according to which the new stage arises not from the unfolding of the potentials contained in the preceding stage, but from actual clashes between the organism and its environment, and from living adaptation to the environment.

We regard the idea that the structure of the development of behaviour in some respect resembles the geological structure of the earth's crust as one of the theoretically

most fruitful ideas, which genetic psychology is mastering before our very eyes. Investigations have established the presence of *genetically different strata* in human behaviour. In this sense the "geology" of human behaviour is undoubtedly a reflection of the "geological" origin and development of the brain.

If we turn to the history of development of the brain, we shall see that, as the higher centres develop, the lower, older centres do not just move aside, but continue to work as subordinate instances under the direction of the higher centres so that in an intact nervous system they cannot usually be set apart.

Another regularity in the development of the brain is what may be called a *passing of the functions upward*. The subordinate centres do not fully retain the initial type of functioning they had in the history of development, but transfer an essential part of their former functions upward, to the new centres being constructed over them. Only when the higher centres are damaged or functionally weakened do subordinate centres become independent and show elements of their ancient type of functioning which they have retained.

Thus we see that, as the higher centres develop, the lower centres persist as subordinate centres and that the brain develops according to the laws of stratification and addition of new storeys over the old ones. An old stage does not die away when a new one arises, but is eliminated by the new one, is dialectically negated by it, passing into the new one and existing in it. Similarly an instinct is not destroyed, but is "eliminated" in conditioned reflexes as a function of the old brain in the functions of the new. Similarly a conditioned reflex is "eliminated" in intellectual action, simultaneously existing and not existing in it. Science is faced with two entirely equal problems. It must be able to disclose the lower in the higher, but it must also be able to reveal the maturation of the higher from the lower.

The history of development of signs brings us to a much more general law governing the development of behaviour. The essence of this law is that in the process of development the child begins to practise with respect to himself the same forms of behaviour that others formerly practised

with respect to him. The child himself learns the social forms of behaviour and applies them to himself. With regard to the sphere under consideration we might say that this law does not anywhere prove so effective as in the use of the sign. The sign is always primarily a means of social relation, a means of influencing others, and only then a means of influencing oneself. Many factual relations and dependences which form this way have been established in psychology. By way of example we may point out the circumstance which was in its time mentioned by Baldwin and has now been developed in Piaget's investigation. This investigation has shown that there is an indubitable genetic connection between the child's arguments and his reflections. This is confirmed by the child's logic itself. The proofs first arise in the arguments between children and are then transferred within the child, connected by the form of manifestation of his personality. The child's logic develops only with the increasing socialisation of the child's speech and all of the child's experience. In this connection it is interesting to note that the genetic role of the collective changes in the development of the child's behaviour, that the higher functions of the child's thinking first manifest themselves in the collective life of children and only then lead to the development of reflection in the child's own behaviour. Piaget has found that precisely the sudden transition from preschool age to school age leads to a change in the forms of collective activity and that on this basis the child's own thinking also changes. "Reflection," says this author, "may be regarded as inner argumentation. We must also mention speech, which is originally a means of communication with the surrounding people and only later, in the form of inner speech, is a means of thinking, in order that the applicability of this law to the history of the child's cultural development should become perfectly justified."

But we would say very little about the significance of this law if we could not show the concrete forms in which it manifests itself in the sphere of cultural development.

If we consider this law, we will see very clearly why all that is internal in the higher mental functions was at one time external. If it is true that the sign is initially a means of communication and only then becomes a means of behaviour of the personality, it is perfectly clear that the

cultural development is based on the use of signs and that their inclusion in the general system of behaviour initially occurred in a social, external form. In general we may say that *the relations between the higher mental functions were at one time real relations among people.* I act with respect to myself as people act with respect to me. As verbal thinking is a transfer of speech within, as reflection is a transfer of argumentation within, so can the mental function of the word, as Janet has shown, never be explained other than by using for the explanation a vaster system than man himself. The original psychology of the functions of the word is a social function, and, if we want to trace the function of the word in the behaviour of the personality, we must consider its former function in the social behaviour of people.

We are not deciding beforehand the question of how essentially correct the theory of speech suggested by Janet is. We merely want to say that the method of investigation suggested by bim is entirely incontestable from the point of view of the history of the child's cultural development. According to Janet, the word was originally a command for others, then it passed through a complex history consisting of imitations, change in functions, etc., and was only gradually separated from the action. Janet holds that it is always a command and that is why it is the principal means of mastering behaviour. That is why, if we want to elucidate genetically whence comes the volitional function of the word, why the word subordinates to itself the motor reaction, whence the power of the word over the behaviour, we shall inevitably arrive in the ontogenesis, as well as in the phylogenesis, at its actual commanding function. Janet says that behind the power of the word over the mental functions stands the actual power of a superior over an inferior and that the relations of the mental functions must be ascribed to the actual relations among people. Regulation of other people's behaviour by means of the word gradually leads to elaboration of verbalised behaviour of the personality itself.

But speech is the central function of social relations and of the cultured behaviour of the personality. That is why the history of the personality is particularly instructive, and the transition within from without, to the individual function from the social is here especially clear.

It is not without reason that Watson sees the essential difference between internal and external speech in that internal speech serves for individual and not for social forms of adaptation.

If we examine the means of social intercourse, we shall find that the relations among people are also of two kinds. Both direct and mediated relations among people are possible. The direct relations are those based on instinctive forms of expressive movement and action.

One animal influences another either by means of actions or by means of instinctive automatic expressive movements. Contact is established through touch, cries or looks. The entire history of the early forms of the child's social contact is replete with examples of this kind, and we see contact established by means of a cry, grasping at the sleeve, and looks.

On a higher stage of development, however, are the mediated relations among people, and their essential indication is the *sign* by means of which communication is established. It goes without saying that the higher form of communication mediated by the sign grows out of the natural forms of direct communication, but they are essentially different just the same.

Thus imitation and division of functions among people form the main mechanism of modification and transformation of the functions of the personality itself. If we examine the initial forms of labour, we shall see that in them the function of execution and the function of control are separated. The important step in the evolution of labour is that what the slave-driver and the slave do is combined in one person. This, as we shall see below, is the main mechanism of voluntary attention and labour.

In this sense all of the child's cultural development goes through three main stages which, by using the dismemberment introduced by Hegel, we may describe as follows:

Let us examine, for example, the history of development of the pointing gesture which, as we shall see below, plays an extraordinarily important part in the development of the child's speech and is generally in large measure an old basis for all higher forms of development. By investigating its history we shall find that in the beginning the pointing gesture is merely an unsuccessful grasping movement aimed at an object and signifying forthcoming action. The

child tries to grasp too distant an object, but its hand reaching for the object remains hanging in the air and the fingers make grasping movements: this situation is the point of departure for the entire subsequent development. Here for the first time arises the pointing movement which we may with good reason conditionally call a pointing gesture in itself. Here is only the child's movement objectively pointing at the object and nothing else.

When the mother comes to the aid of the child and comprehends his movement as a pointing gesture the situation essentially changes. The pointing gesture becomes a gesture for others. The child's unsuccessful grasping movement gives rise to a reaction not from the object, but from another person. The original meaning to this unsuccessful grasping movement is thus imparted by others. And only afterwards, on the basis of the fact that the child associates the unsuccessful grasping movement with the entire objective situation, does the child himself begin to treat this movement as a pointing gesture. Here the function of the movement itself changes: from a movement directed toward an object it becomes a movement directed toward another person, a means of communication; the grasping is transformed into a pointing. Owing to this the movement itself is reduced and a form of pointing gesture is elaborated about which we may with good reason say that it is already a gesture for oneself. However, this movement becomes a gesture for oneself not otherwise than by being at first a pointing in itself, i.e., by objectively possessing all the necessary functions for pointing and a gesture for others, i.e.. by being comprehended as a pointing by the surrounding people. The child is thus the last to realise his own gesture. Its meaning and function are created first by the objective situation and then by the people surrounding the child. Thus, the pointing gesture first begins to indicate by movement that which is understood by others and only later becomes a pointing gesture for the child himself.

Thus, we may say that *we become ourselves through others* and that this rule applies not only to the personality as a whole, but also to the history of every individual function. This is the essence of the process of cultural development expressed in a purely logical form. The personality becomes for itself what it is in itself through what

it is for others. This is the process of the making of the personality. Here for the first time in psychology the problem of correlations of the external and internal mental functions appears in all its enormous importance. Here, as was already mentioned, it becomes clear why all the internal was in the higher forms necessarily external, i.e., was for others what it is now for oneself. Any higher mental function necessarily goes through the external stage in its development because it is originally a social function. It is the centre of the whole problem of internal and external behaviour.

For us to say "external" about a process is to say "social". Any higher mental function was external because it had been social before it became an internal, mental function proper; it was formerly a relation between two people. The means of influencing oneself is originally a means of influencing others or a means of influencing the personality by others.

In a child it is possible to trace step by step the alternation of these three main forms of development in the function of speech. To begin with, the word must have meaning, i.e., a relation to a thing, there must be an objective relation between the word and what it means. If this is absent, further development of the word is impossible. Then this objective connection between the word and the thing must be functionally utilised by the adult as a means of communication with the child. Only then does the word become meaningful for the child itself. Thus the meaning of the word first objectively exists for others and only afterwards begins to exist for the child himself. All the main forms of speech communication between the adult and the child later become mental functions.

We might formulate the general genetic law of cultural development as follows: *any function in the child's cultural development appears on the stage twice, on two planes, first on the social plane and then on the psychological,* first among people as an *intermental category* and then within the child as an *intramental category*. This equally applies to voluntary attention and logical memory, formation of concepts and development of volition. We have good reason to consider this proposition a law in the full sense of the word, but it stands to reason that the passage within from without transforms the process itself, changes

its structure and functions. Behind all higher functions and their relations genetically stand social relations, real relations of people. Hence one of the main principles of our will is the principle of division of functions among people, division in two of that which is now blended in one, experimental unfolding of the higher mental process into the drama which is taking place among people.

We might therefore designate the main result to which we are brought by the history of the child's cultural development as a *sociogenesis of the higher forms of behaviour.*

The word "social" applied to our subject is very important. In the first place, it means in the broadest sense of the word that all the cultural is social. Culture is a product of man's social life and social activity, and the very statement of the problem of cultural development of behaviour therefore already brings us directly on to the social plane of development. We might further point out that the sign which is outside the organism is like a tool separated from the personality and is essentially a social organ or social agency. We might, furthermore, say that all the higher functions have formed not in biology, not in the history of pure phylogenesis, and that the very mechanism underlying the higher mental functions is a copy of the social. All the higher mental functions are interiorised relations of a social order, the basis of the social structure of the personality. Their composition, genetic structure and mode of action, in a word, all of their nature is social; even when transformed into mental processes it remains quasi-social. Even when alone man retains the functions of communication.

By changing Marx's well-known proposition we might say that man's psychological nature is a totality of social relations which have been transferred within and have become functions of the personality and forms of its structure. In this proposition we see the fullest expression of all to which we are brought by the history of cultural development.

PROBLEMS OF PSYCHOLOGICAL THEORY

By S. L. RUBINSTEIN

1

The act which determines the right of a new field of knowledge to existence consists in discovering or singling out a definite range of phenomena which develop or function in accordance with their own inner laws. Marxism has asserted itself as a science about social phenomena because it revealed the specific laws which govern them. This similarly applies to every discipline which rises to the level of a science.

The main task of any theory, including psychological theory, is to disclose the principal specific laws which govern the phenomena in question. Every theory is built on a certain conception of determination of phenomena.* The theoretical basis for our approach to the construction

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* Cybernetics, since it is a study of "information" or feedback, is a study of one type or aspect of determining processes. It is precisely this that accounts for its universal applicability to various fields. It is a study of determination of processes in the course of which each successive process is conditioned by the results of the preceding one. In precybernetic machines, machines without feedback, each action of a machine was conditioned by its structure and did not depend on its preceding actions; in cybernetic machines the "information" of the results of each action of the machine concerning the changes wrought by it is included in the conditions on which the next action of the machine depends. The claims of cybernetics that the most diverse fields of knowledge (theory of machines, physiology of the brain, social sciences) or types of processes studied by them are "subordinate" to it are based on the fact, or signify only the fact that in all these fields there are processes whose determination reveals this dependence of each successive action on the results of the preceding action; the changes wrought by the result of one process or action form part of the conditions which determine the successive process or action. Cybernetics, the study of information or feedback, is a study of one definite type or aspect of determination. This is, at any rate, its kernel, its essence; all the rest of it is engineering. Cybernetics is but a particular case of the general study of determination of processes and phenome-

of psychological theory is the principle of determinism in its dialectical-materialist conception. It may be briefly formulated in a single proposition: external causes act through internal conditions. This removes the antithesis between the external conditionality and the internal development or self-development (self-motion). It is precisely the relationship between the external and internal connections that form the basis of all phenomena, including mental phenomena.

Attempts are often made to connect the concept of determinism with the mechanistic concept which dominated science in the 17th and 18th centuries. It was based on the conception of cause as an external impetus which directly determines the effect produced by it in another body or phenomenon. This mechanistic theory of determinism could only ostensibly, with a certain degree of approximation, be applied in classical mechanics to the mechanical motion of the point. It turned out that in this form it was not always applicable already in quantum mechanics. It is clearly unable to give an adequate explanation of organic life. Here the same action produces different effects in organisms with different properties and in the same organism under different conditions. The effect of an external action depends on the internal state of the organism on which this action is exerted. This circumstance applies to all organic phenomena and even more so to mental phenomena.

Thus the fundamental weakness of mechanistic determinism is that it endeavoured—unsuccessfully—to establish a direct dependence of the end result of an external influence on the influence itself, disregarding the internal conditions of the phenomenon (or body) on which this influence was exerted. The expression of the mechanistic conception of determinism in psychology is the original scheme of strict Watsonian "stimulus-response" behaviourism. The weakness of the mechanistic conception of determinism is utilised by indeterminism which has long since consolidated

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na. Elaboration of this latter case in all its multiformity is fraught with enormous possibilities and offers unlimited prospects. Elaboration of the study of determination is one of the greatest tasks of science. Here we foresee fundamental possibilities of constructing a system of algorithms for various aspects or instances of determination of phenomena.

itself in idealist psychology and is now, as is well known, making inroads into physics—quantum mechanics.

Surmounting the mechanistic conception of determinism dialectical-materialist determinism notes the importance of internal conditions and, by emphasising their connections with the external conditions, cuts the ground from under indeterminism, depriving it of its main arguments. I. P. Pavlov's theory may serve as an example of determinism of the new type. To make this clear, it is necessary (perhaps more than is usually done) to emphasise in Pavlov's conception one aspect which is not always clearly enough realised and properly elucidated.

It is usually said that Pavlov's theory proceeds from the external relations of the organism to its environment, with the conditions of its life, and that the very brain (its higher parts) serves to effect these external relations. But Pavlov was able to create a scientific theory, a true teaching on these external relations of the organism to its environment, to reveal the laws which govern them, only because he studied the internal laws of cerebral activity which mediate these external actions on the organism and its reactions. Pavlov's theory reveals the external relations of the organism to the conditions of its life in their regularities precisely because it discloses the internal interrelations of the processes by which these external relations are mediated.

Pavlov's theory found a specific form of expressing this general principle which meets the requirements of physiological study of higher nervous activity.

The problem of psychology is to find for the same philosophical principles which underlie the theory of higher nervous activity a new form of their manifestation specific of psychology. The community of principles which would take part in the science of higher nervous activity and psychology is the only reliable basis on which psychology might "fit" the theory of higher nervous activity and lock with it without any detriment to the specificity of either of these sciences.

The "reflex" conception of mental activity means that mental activity is externally conditioned response activity; it is externally conditioned response activity of the human brain. This means that mental phenomena are determined by the interaction between man, as subject, and the

objective world. This proposition contains in a concise and particular form the idea which was given detailed and generalised expression in the dialectical-materialist conception of the principle of determinism.

This general principle is realised as multifariously as is multifarious the nature of the phenomena which enter into interaction. In this community, as a philosophical principle, it applies not to one special field of phenomena, but to all phenomena. In each special field of phenomena it must therefore receive its special form of manifestation in conformity with each special form of interaction. In building psychology on the basis of dialectical materialism it is necessary to find the special form of manifestation which the dialectical-materialist principle of determinism must assume in conformity with mental phenomena. The solution of the problem of this specific form of its manifestation rests on the problem of the relationship between the physiologic and the mental, the theory of higher nervous activity and psychology.

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In the course of development of the reflex activity of the brain new, mental, phenomena—sensations, perceptions, etc.—emerge and thereby naturally give rise to a new object of study and new problems of its investigation—problems of psychology.

The reflex activity of the cortex is at the same time also nervous (physiologic) and mental activity (since it is the same activity viewed from different aspects). This reflex activity is studied therefore, first, as nervous activity determined by physiologic laws of neural dynamics (processes of excitation and inhibition, their irradiation, concentration and mutual induction) and, secondly, as mental activity (as perception and observation, memorisation, thinking, etc.). However, here, as in general, the determining subject matter of the science is its highest, i.e., more specific characteristic.

Each science studies the phenomena of reality in relations specific of the given science. For physiology reality is the aggregate of *stimuli* acting on the brain, on the analysers; for psychology it is the objects of cognition and action, objects with which *man* interacts as *a subject*.

At first, before the appearance of the organism capable of reacting to stimuli, being, reality exists as processes and things. With the appearance of organisms the phenomena of the material world (things, processes) also form *stimuli* correlatively with the organisms on which they act. This interaction takes place on an "ontological" plane. As long as things appear only as stimuli there is as yet no gnosiological plane; there are as yet neither objects nor subject in the proper sense of the word. When stimuli act on organisms which have receptors (analysers, sense organs) sensations arise in the response activity of the latter.

Stimuli reflected in sensation may act as signals which are not realised as objects. Experimental proof of this is found in experiments which attest that the subject may correctly react to a sensory signal without being aware of the signal to which it responds (E. Thorndike, L. I. Kotlyarevsky and others). Phenomena (things, processes) which are stimuli and act on the organism, its organs (analysers) as such are realised when they act as *objects*. Realisation of a thing or phenomenon as an object is connected with the transition from sensation, which serves only as a signal to action, to reaction, to sensation and perception as an image of the object (or phenomenon).

Consciousness proper (as distinct from the mental in general) begins with the appearance of the image of the object in the special gnosiological sense of this term.

Stimuli reflected in sensation, in consciousness, act as *objects*. The concept of object is a gnosiological category; the concept of stimulus is a physiological category. Since all of the scientific consideration of the world cannot be reduced to a physiological consideration of the world, but necessarily includes the gnosiological and psychological aspects, the concept of object cannot be reduced to the concept of stimulus.*

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* This differentiation of the concepts of stimulus and object associated with the differentiation of the physiological, on the one hand, and the gnosiological and psychological aspects of scientific consideration of the interrelations between the individual and his environment, on the other hand, is a matter of principle. That is why a mere failure to understand the meaning of this differentiation of concepts and aspects would be attested by an attempt, recognising a possibility of substituting a simple stimulus for an object, to substitute a complex stimulus for it. The latter is in the same plane of physiologic relations as a simple stumulus; just as a simple stimulus it cannot replace

The relation to the object is important from both the gnosiological and psychological standpoints. The difference between the gnosiological and psychological points of view is that gnosiology makes the object of its study this very relation to the object, while psychology deals with the mental process in this relation to the object.

The specific tasks of psychology begin in connection with the transition to the study of man's mental activity performed by the brain. *Psychology* studying mental activity *is one of the sciences about man*. It is the science which reveals the laws governing man's mental activity performed by the brain.

Two fundamental propositions determine our approach to human psychology. They are, first, the conception of mental phenomena in general as a product of *development* of the material world and, secondly, the conception of human psychology in its specific features as a *socially-conditioned* product of history.

The problem of the place of psychology in the system of sciences is usually complicated by the attempts to solve it on the basis of opposing the natural sciences to the social sciences, excluding any connections between them. Moreover, in the term "social sciences" the finer differences between the social sciences proper and the sciences dealing with socially-conditioned phenomena, which include human psychology, are effaced. Psychology is one of the sciences about the *nature* of man, a socially-conditioned

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and eliminate the gnosiological aspect of the problem (which is also connected with its psychological aspect).

Nor can this proposition be altered by the fact that Pavlov's physiology deals not only with stimuli as such, but also with their signalling role. This latter circumstance is really very important for it reveals the physiological mechanism of perception of the most important "functional" properties of the object, which characterise it in its practical relations to the life and activity of the individual. But here, too, we remain in the sphere of physiologic relations and *physiological study of perception of the object*. But must an explanation of a fact serve to liquidate it? Of course, there are cases when an explanation of something, which was accepted as fact, reveals the illusoriness of the supposed fact. But a physiological explanation of the perception of an object cannot be transformed into a negation of the gnosiological relations which are analysed by physiology. The true scientific meaning of Pavlovian concepts and laws does not, of course, consist in replacement and, consequently, disaffirmation of the gnosiological categories (and the psychological categories associated with them).

product of history. This conditions the connection of psychology with the sciences about nature (primarily the theory of higher nervous activity) and with the social and historical sciences.

Since mental activity is an activity performed by the brain it is subject to all laws of neurodynamics; without these laws mental phenomena cannot be fully explained. Psychological investigation cannot be opposed to the physiologic study of neurodynamics or be isolated from it; explanations of mental phenomena must take into consideration and utilise all the results of physiologic investigation of neurodynamics. At the same time the products of this neurodynamics, the resultant new mental phenomena, condition the new plane of psychologic investigation in which the processes studied by the physiologic theory of higher nervous activity appear in a new specific quality. Taken in this quality they are determined by the relations from which physiology is abstracted.

For example, learning, i.e., memorisation organised in a definite manner, examined on the physiological plane, is organised presentation of stimuli which act on the brain. It is therefore subject to all laws of neurodynamics of the cortical processes. But when we explain the result of learning by the action of these laws we abstract ourselves from a number of relations which are characteristic of learning as a special form of mental activity. When the same process, which on the physiological plane is a response of the brain to the presentation of stimuli organised in a definite manner, is regarded as learning in a psychologic investigation, new dependences inevitably appear—a dependence on man's activity, on the relations into which man enters in the course of this activity, on what he memorises (for example, material taught at school, other people, the teacher, the school collective, etc.). It is in these new dependences that the given process is studied by psychology. Each psychological investigation discloses one of the dependences of this type, whereas physiology abstracts itself from them. To organise man's activity, it is particularly important to know precisely these dependences and laws which govern them. It is the task of psychology to reveal them.

We have mentioned the fact that physiology abstracts itself from the relations which are essential to mental

phenomena as such. This means that physiologic phenomena are polysemantic with respect to mental phenomena taken in properties and relations specific of them. Different in their concrete expression mental phenomena are subject to the selfsame physiologic process. Moreover, there is no point correlation between mental and physiologic processes or phenomena; each concrete mental process in its physiologic expression is represented by a rather complex dynamic system or an aggregate of various physiologic processes. In virtue of this it is entirely impossible, without losing the specific differences between one mental process or phenomenon and others, to substitute for some mental phenomenon a "corresponding" physiologic phenomenon as its adequate equivalent capable of differentiating the given mental phenomenon from others, differing from it on the psychological plane. A whole scale of various psychologic values always corresponds to the selfsame value of variable physiologic laws figuring in formulas. That is why, while remaining inseparable from physiologic processes, mental phenomena differ from them just the same. Physiologic and psychologic laws cannot be directly brought to coincidence by the use of physiologic terms in psychologic laws. Physiologic terms are not adequate to the relations expressed in psychologic laws.

Governed by physiologic laws of higher nervous activity (laws of dynamics of nervous processes) mental phenomena appear as the effect of the action of physiologic laws just as physiologic, or generally biologic, phenomena, which are subject, for example, to laws of chemistry, are the effect of the action of chemical laws. However, physiologic processes are a new specific form of manifestation of chemical laws, and it is precisely this new, specific form of their manifestation that appears in the laws of physiology. Mental phenomena are similarly a *new, specific form of manifestation of the physiologic laws of neurodynamics, and this specificity is expressed in the laws of psychology.* In other words, mental phenomena remain specific mental phenomena and at the same time are a form of manifestation of physiologic laws just as physiologic phenomena remain physiologic, but, as a result of biochemical investigation, also appear as a form of manifestation of laws of chemistry. The lower laws are included in the higher spheres, but only as a subordinate factor which does not

determine their specificity. Such is in general the correlation between the "lower" and "higher" spheres of scientific investigation. The more general laws of the lower spheres apply to the higher spheres, but do not exhaust the laws of the latter. The leading laws of each sphere are its specific laws which determine the leading specific properties of the given sphere of phenomena.

As a result of the disclosure of the biochemical nature of physiologic phenomena these phenomena do not disappear as specific phenomena, but the knowledge of them is deepened. Reflexes do not cease to be reflexes however deeply the biochemical laws governing the coupling of cortical connections may be revealed. The same thing must be said about any physiologic phenomena. For example, the progress made by biochemistry of digestion will deepen the knowledge of this process and the latter will appear as a specific effect of chemical reactions, but it will remain a *specific form* of their manifestation—a process of digestion—just the same, characterising in this specific form the life of living beings and not the reactions of chemical elements. The nature of phenomena is always determined by the specific laws which govern them.

Similarly, as a result of neurodynamic analysis, mental phenomena appear as the effect of the action of neurodynamic laws governing the reflective activity of the brain. But this does not eliminate the specificity of mental phenomena. The knowledge of the laws established by psychological investigation does not lose its significance merely because mental phenomena appear as the effect produced by the action of the laws governing higher nervous activity. The interrelation between psychology and the theory of higher nervous activity fits in the general framework of the interrelation between the "lower" and "higher" spheres of scientific knowledge.

The relation between psychology and the theory of higher nervous activity is analogous not to that between biology and chemistry, but to that between biology and biochemistry. The theory of higher nervous activity also studies mental activity, but it does so in a special aspect. The laws governing higher nervous activity play an important role in explaining mental activity. However, they do not exhaust its laws and are not its specific laws, i.e.,

laws determining its leading specific properties. Such are the laws of psychology.

This concept of correlation of the physiologic and psychologic laws, the physiologic and psychologic characteristics of cerebral activity shows the untenability of a number of current formulations.

The first obviously untenable formula is the one in which the mental and the physiologic are regarded as two coordinated aspects of one process. Its erroneousness consists in the fact that it disguises the hierarchy of the primary and the derivative, the basis and the forms of its manifestation which express the essence of the relations between the physiologic and psychologic characteristics and erroneously conceives them as equally correlated, coordinated, parallel. Its error consists in the fact that it shows the various "aspects" and does not show the correlation between these "aspects".

Untenable also is the proposition which was sometimes opposed to this formula. According to this proposition, the physiologic and psychologic characteristics are serial "components" of the characteristic given to mental phenomena by psychology, while physiology limits itself to their specific (physiologic) characteristic. By its theoretical content this proposition expresses the concept of old "physiologic psychology", simultaneously mechanistic and idealist. The arrangement of the physiologic and psychologic characteristics in series, or the inclusion of the former in the latter leads to the fact that the physiologic characteristic of phenomena loses its effectiveness since in such serial arrangement of the physiologic and psychologic data mental phenomena do not appear in their specificity as a *new, specific form* of manifestation of physiologic laws which is expressed in the laws of psychology. The search for the specificity of psychologic laws from this point of departure is therefore expressed in a fundamentally wrong *opposition* of psychologic laws to physiologic laws. This uneven opposition of these laws and their separation from each other are but another expression of their initial external serial combination.

Very widespread, but fallacious, is also the formula according to which the physiologic laws of neurodynamics apply only to the material basis of mental phenomena, while the psychologic laws apply to mental phenomena

which form a "superstructure" on this material physiologic basis. This formula is particularly harmful and dangerous because, by characterising the physiologic laws governing higher nervous activity as the "basis" of psychology, it appears, by its external expression, close to the true concept of the correlation between the physiologic and psychologic laws. In reality, however, according to its inner meaning and actual trend, it expresses emphatic dualism. It establishes, as it were, in the vertical direction (from the physiologic "basis" to mental phenomena which form a "superstructure" on it) the same external serialness between them as the preceding formulas establish in the "horizontal" direction. According to the meaning of this formula, the laws governing higher nervous activity do not at all apply to mental phenomena, but only to their physiologic "basis", to physiologic phenomena. According to this formula, mental phenomena do not at all appear as a form of manifestation of neurodynamic laws. The connection between them is severed. This is a restoration of the old scheme, at the same time mechanistic and idealist. The entire content of Pavlov's theory of higher nervous activity, the entire course of development of science disproves the conception concealed in this formula.

3

The ways of psychological investigation, as also any scientific investigation in general, are always more or less consciously determined by the theoretical conception which underlies it. This theoretical conception determines the structure of the investigation. What must the structure and ways of psychological investigation be?

The decisive factor here must be the dialectical-materialist conception of determinism. The direct expression of this conception is the proposition that external causes act through internal conditions.

It is not difficult to show that precisely this proposition determines the "model" of investigation which was realised by Pavlov in his theory of higher nervous activity. It is usually—and very correctly—emphasised that Pavlov conceived the activity of the brain as effecting the external relations between the organism and the conditions of its life. But it is no less important to emphasise that Pavlov

was able to disclose the laws governing these external relations only because by studying them he discovered the internal laws of neurodynamics of the cortical processes, the laws of their own operation (laws of irradiation and concentration) and their interrelation (law of induction). Without knowledge of these internal laws it would have been possible to state only descriptively that such and such external action caused in the given case such and such reaction (directly correlating them according to the stimulus-response scheme). At best it would have been possible to indicate groups or types of actions, correlating with them also descriptively chosen groups or types of reactions. This, as is well known, is the course pursued by behaviourism. Unlike Pavlov, it follows the mechanistic stimulus-response scheme. Description of external correlations between the stimulus and response answers the purpose of the *pragmatic*, generally *positivist* methodology from which the behaviourists proceed. This course does not lead to disclosure of the actual laws. In the course of Pavlovian investigations the phenomena being studied (secretion of saliva in response to a stimulus, formation of a conditioned bond) are transformed into indicators of the regularities which underlie them. Refracted through the internal relations, through the internal regularities of cerebral activity, the external correlations between the organism and the conditions of its life appear in Pavlov's theory in their actual regularities. Only this course leads to real scientific knowledge. Only by disclosing the internal laws governing the neurodynamics of the cortical processes did Pavlov create a scientific theory—the *theory* of higher nervous activity.

Nor must it be different in psychology. The science of psychology cannot be built in any other way, on the basis of any other "model". The fundamental weakness of psychological theory is precisely that psychology has not yet consciously followed the course of such construction of its investigations.

By way of example let us take the study of thinking. In literature, particularly that devoted to the thinking of schoolchildren, we find indications of cases of presence or absence of transfer of a solution from one problem to another, analogous problem. These are facts which the teacher encounters in his day-to-day work with pupils in

school, and they are very important facts for judging of their thinking. Presentation of the problem under modified conditions is usually given as the cause of transfer or nontransfer. The result of such investigations may be roughly, schematically and therefore, of course, in an oversimplified manner expressed as a dependence of transfer on modification of conditions. But transfer is, in fact, a metaphorical description of some external occurrence without disclosure of its inner psychological content. *Psychologically* transfer is *generalisation*, whereas modification of the conditions under which the pupil is given the problem is a description not of the pupil's, but of the teacher's action. To connect transfer with modification means directly to correlate the external action (the teacher's activity of modifying the conditions of the problem) with the result of the pupils' thinking and omit the latter, i.e., to construct the explanation according to the stimulus-response scheme without disclosing the inner content of thinking, its inner regularities.

What meaning can modification of conditions have with respect to the pupil's thinking? Only one meaning: modification creates favourable conditions for *analysis*, for distinguishing the essential conditions from the nonessential conditions, i.e., the conditions of the problem in their proper, exact meaning from the attendant circumstances under which the problem appears in the particular case. Behind the modification-transfer dependence we encounter another dependence—an *analysis-generalisation* dependence.

Let us take another example with a different run of thoughts. Thinking is treated as a totality of mental actions and the mental actions themselves as a series in the process of development of scientific knowledge of socially-elaborated methods of solving mental problems learned in the process of instruction, etc. (we designate this run of thoughts again as roughly, schematically and in as oversimplified a manner as the former). In this theory of thinking, learning, i.e., acquisition of knowledge and skills (methods of solving problems) in the process of instruction, is pushed into the foreground. It goes without saying that acquisition of knowledge and skills is a matter of capital importance and formation of thinking outside of it is impossible. But what does this learning occurring

in the process of instruction actually mean? It is a certain pedagogical fact. Remaining on the plane of studying but this fact, investigation naturally turns upon the description of the stages of learning and the conditions on which its success depends as its main task. The investigation is in danger of remaining essentially in the sphere of pedagogical problems. In order to pass on to the plane of psychological investigation proper, it is necessary to establish what learning means psychologically, i.e., to disclose the internal psychological content, the inner regularities of the pupil's thinking as a result of which learning takes place. *Psychologically* acquisition of knowledge is thinking —analysis, synthesis, abstraction and generalisation—taking place under conditions of instruction.

Elementary thinking operations take place on the plane of practical action (counting with the hands) and later on the mental plane (counting in the head): but this is a mere statement of fact. In a psychological investigation it must be psychologically analysed. *Psychologically* the transition from "external action" to "internal action" is a process of generalisation and abstraction whose movement must be traced.

Thinking directly appears in the form of numerous and various operations. Each of them must be given special study and explanation, taking its specificity into account. In order that all these specific explanations of specific operations may finally lock up in one general theory of thinking, it is necessary that all specific operations should occur, without losing their specificity, as the acts of analysis and synthesis, as well as the processes of generalisation and abstraction, under different conditions, on different material, and on different levels. They are, as it were, "common denominators" of multifarious thinking, which make it possible to give thinking a generalised interpretation. Analysis and synthesis and their derivatives—generalisation and abstraction—are necessary concepts of the general theory of thinking. In studying thinking it is necessary to trace their movement.

To characterise any mental activity in psychology means, in the final analysis, to show it as a derivative of the activity of analysis, synthesis, etc. In their turn, analysis, synthesis and generalisation assume various forms and produce different results, depending on the system of concrete

thinking in which they appear. The law-governed correlations between analysis and synthesis and their derivatives—generalisation and abstraction—constitute the basic inner regularities of thinking.

The task of psychological investigation is to reveal these main internal regularities which do not exhaust what is required to explain thinking, but which are absolutely necessary to explain it. Thinking, like any other human activity, must be conceived on the basis of external relations forming in man in the process of instruction, acquisition of the knowledge accumulated by mankind, the correlation with the tasks encountered by man in the course of social life, studies, etc. But without disclosing the internal regularities, the internal correlations through which these external relations are refracted, it is impossible to understand human thinking or these very relations in their regularity.

There are no two ways of constructing a psychological theory: one resting on internal thinking correlations, and another, oriented on the external relations of thinking to the object. There is one—and only one—way of psychological investigation and construction of a true theory of thinking. It consists, through studying the external relations between thinking and the object, and the tasks encountered in these cases, in disclosing the inner laws of thinking and, by refracting the external relations through these inner laws of thinking, in understanding these very relations in their regularity.

On the basis of the internal laws of generalisation alone it is impossible to determine *what* will be generalised and according to what principles. It depends on the special features of the objects and the external relations which will form between the subject and the object. But without the internal regularities it is impossible to understand *how* the generalisation will take place and what result it will produce. The external relations appear as regular only when the internal relations, their regularities are disclosed.

Such is in principle also the question concerning psychological theory; it is necessary to express the vital phenomena in psychological concepts, singling out the aspect which constitutes the special subject of psychological investigation; it is necessary to express the dependence between them by means of internal psychological regular-

ities and thus to proceed to a psychological understanding of the regularities of initial external relations of man to the objective world and other people, his relation to social experience, the system of knowledge acquired in the process of instruction, etc.

4

We have outlined the structure of psychological theory. The question is: what forms its content? It is necessary to sketch at least the main features of it.

The central place in the system of psychology must be occupied by the mental *as a process*, *as activity*. (This Sechenov proposition remains valid.) By mental, as activity, we imply the mental process or totality of processes which satisfy some vital human requirement and are directed towards a definite goal more or less directly connected with the satisfaction of this requirement. It is therefore a question of the activity of *man, subject, personality*, and not merely of some organ (even the brain), of *human* activity performed by the brain. Such activity may be, for example, esthetic perception or thinking since they satisfy the esthetic or cognitive requirements of man and are directed toward this goal. A mental process, which is itself not human activity in this sense, always forms part of some other activity and depends on it. The study of the mental, as a process or activity, is the first task of psychology. It also includes the study of consciousness as a process of realisation of the world.

A properly conceived study of the mental, as a process or activity, eliminates the abstract idealist functional conception of psychology. The "functions" of so-called functional psychology, whether memory or imagination, attention or volition, are mental processes transformed into mental actors. Whereas in idealist psychology the subject in general, the actor, instead of man himself, is his consciousness, in idealist functional psychology various aspects of mental activity become the special actors, the subjects of the corresponding activities. Consciousness is transformed into a stage on which these actors appear and externally interact with each other.

The construction of scientific psychology requires elimination of these "actors" and disclosure of the regularities

of mental activity and its various aspects covered up by these fictitious actors.

Let us take, for example, imagination. For functional psychology it is a special actor. Regularities or special operations of transforming reflective activity are ascribed to it as its properties. Any act of reflection of an object by a subject performed by analysis and synthesis, abstraction and generalisation is necessarily not a mechanistic reproduction of the object, but its more or less considerable ideal—sensuous, mental—transformation. In the image of the object some of its aspects are accentuated and brought to the foreground, while the perception of others is inhibited as a result of negative induction on the part of "strong" stimuli. They are "disguised" and are brought to nought. The image of the object is thus improved, modelled, transformed in the very process of perception, depending on the relation between the subject and reflected object, the vital importance of the latter to the subject and the relation of the object to him. "Imagination", i.e., the process of transformation of the image of the object, is an aspect—and a very *important* aspect at that—of *any* process of sensuous reflection of reality. Then it is transformed from the involuntary process, as it appeared at first, into a so-called voluntary process, i.e., consciously regulated in accordance with a definite intention, and from the plane of perception passes to the plane of conception. The task of scientific investigation is to study the general and special regularities of this process of transformation (which forms an aspect of the single general process of man's mental reflection of the world). Transformation of imagination from a process or, to be exact, from a specific aspect of the process of man's mental reflection of the world into a special actor is, to say the least, a useless and idle procedure because the "properties" of this "actor" may still be determined only by disclosing the regularities of the corresponding activity or process. It is a harmful and mystifying affair since reference to imagination (as also to any other "function") makes it appear that it is unnecessary to investigate the regularities of the process, that it is enough to refer to the corresponding "actor" and to "explain" anything without actually investigating or explaining anything by referring to the properties especially for this purpose ascribed to it.

The philosophical sense of functional psychology consists in substituting as a subject for man the various aspects of his mind, his consciousness (which is its fundamental fallacy). Functional psychology is a particular, special expression of the general tendency of idealism to substitute, in the construction of psychology, for man his consciousness, thinking, spirit, etc.

It is clear that to construct a scientific psychology it is necessary completely to do away with functional psychology conceived in this manner.

It should be once more taken into consideration that the concept of function, like the concept of activity and process, expresses a definite conception of determination of the mental processes. The concept of *function* is connected with the conception of determination of the entire process only from *within*. In the so-called psychomorphological conception (as well as in the conception of vulgar materialism) the mental, as a function of the brain, began to be interpreted as a *function* of cellular tissue determined by its morphological structure; in idealist functional psychology the concept of function meant determination of the mental process by properties of the corresponding "actor", i.e., again entirely from within, irrespective of the external world.

Unlike the conception of function, as determined entirely from within, the conception of the mental as a process or activity makes it possible to consider mental phenomena as a result of man's interaction with the world.

Especially emphasising the role of the "internal" conditions of thinking in studying the mental process (see chapter "On Thinking") we thereby create prerequisites for a transition from functional to personalistic psychology.

It is not thinking that thinks, but man, and it is man and not his thinking that is the subject of thinking.

Every mental process is included in man's interaction with the world and takes part in the regulation of his actions, his behaviour; every mental phenomenon is both a reflection of being and a link in the regulation of behaviour, of the actions of people.

What appears as attention and volition in the functional interpretation is actually the regulatory aspect of man's mental activity (for greater details see Chapter 4 "Being and Consciousness").

That is why the sphere of psychological investigation includes the movements, deeds and actions of people, i.e., not only the "mental" activity, but also the practical activity by which people change nature and reorganise society. But the object of psychological study in them is only their specifically psychologic content, their motivation and regulation by means of which the actions are brought to conformity with the objective conditions under which they are performed and which are reflected in sensation, perception and consciousness.

Any mental process, any mental activity is always a connection of the individual with the world. Mental activity always gives rise to that which reflectively represents objective reality, i.e., its image. The image itself, outside the mental process or activity, cannot serve as the object of psychologic investigation. Nor can it exist outside of any process. But under certain conditions it appears for the subject outside of any process since the process in which the image is formed is not realised by the subject. In these cases the task of psychological investigation is to reveal the *process* by changing the conditions of operation of the perceptual process and of considering the formation of the corresponding activity.

Under difficult conditions, as well as during the initial stages of formation of corresponding activity (for example, visual perception of an object or a situation) visual analysis, synthesis, generalisation and, on this basis, interpretation, in a word, the entire mental composition of perception, come to the fore.

Thus the object of psychological investigation is the image indissolubly connected with mental activity. At the same time mental processes, mental activity, may be understood in their specificity only when taken in connection with the image which arises in their course. For example, visual perception stands out in its specificity only in connection with the image which arises in its process.

Receiving concrete expression in the image in which the objective world is reflectively represented, any mental process, on the other hand, presupposes a subject which is also always connected with the objective world. The theory of mental processes and mental activity arrives at insoluble contradictions if, despite their conception, as one of the forms of connection between the subject and the

objective world, it does not lock on to the theory of man's mental properties, if the mental processes do not receive their expression not only in the image of the object, but also in the characteristic of the subject.

The question of the connection between man's mental activity and the mental properties is one of the fundamental questions of psychologic theory. The way to formation of man's mental properties opens only through the connection between these properties and his activity. The ability of psychology to make a more or less appreciable and, at the same time, its own specific contribution to the great cause of educating people and forming their faculties depends, more than anything else, on the correct decision of precisely this question. And yet the theory of faculties, the mental properties of the personality, its psychological characteristics in general, is still the least elaborated part of psychology. Here, more than anywhere else in psychology, substantialisation of the mental is strong and is combined with pseudo-science by means of grossest psychomorphologism which directly correlates the faculties with the morphological structures of the brain apart from the dynamics of reflex activity.

The reflex conception of the mental applies not only to the mental processes, but also to the mental properties. A mental property is an ability under certain conditions to respond by definite mental activity to definitely generalised influences. Application of the reflex conception to the mental properties necessarily leads to the locking of the theory of mental properties with the theory of mental processes.

By personality properties the traditional point of view usually implied only the traits of character or abilities for complex types of occupational activity (that of a musician, mathematician, etc.). These properties were regarded as individual characteristics which set one individual apart from the others. But the consideration of outstanding individual characteristics cannot be severed from the study of the elementary, "generic" properties common to all people. Severed from this ground the outstanding abilities of individual people are inevitably mystified and the way to their investigation is closed. In contrast to such an approach all human properties must be considered in their interconnections, and the consideration must be based on the "generic" properties common to all people.

Such an initial common property is sensitivity in all the diversity of its forms and levels conceived not as a value inversely proportional to the thresholds, but primarily as an ability to respond by sensations and perceptions to definite stimuli under definite objective conditions. It is based on an alloy of unconditioned and conditioned bonds. Any appreciably complex sensory activity, say, visual perception of spatial properties and relations of objects, functions as a whole, including the inborn unconditioned-reflex components, as well as the conditioned-reflex components forming during the individual's lifetime in the process of the given activity. The corresponding activity is necessarily formed together with its "functional organ" (Ukhtomsky)—the functional system adapted to performing the given function (in this case—visual perception of the spatial properties of objects).

In the process of solving this problem consisting in formation of the image of the object, the corresponding mental activity and the "organ" to perform it—the functional system which selectively includes the morphologically (in the analysers) fixed functions and the connections forming on their basis in the process of corresponding activity—are formed. It is such a "functional organ" that forms the neurological basis of the mental property, and this is the property or ability in its physiological expression. The formation of sensory mental activities and the corresponding properties are two expressions of essentially the same process. Physiologically appearing as a system of neural connections the mental properties, as such, exist as naturally occurring mental activity.

One more thing must be added. The mental characteristics of a person (personality) cannot apparently consist in a mere sum of properties each of which is expressed by a psychologically specific response to an action exerted on him. This would mean a complete splitting of the personality and would lead to a fallacious mechanistic concept that each action exerted on man determines its effect "piecemeal", independent of the dynamic situation in which this action is exerted and which is conditioned by other actions. Disclosure of the internal regularities of the dynamic correlations, through which the actions exerted on man are refracted in man, is one of the most important tasks of psychology.

SPECIAL FEATURES OF THE AFFERENT APPARATUS OF THE CONDITIONED REFLEX AND THEIR IMPORTANCE TO PSYCHOLOGY*

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The I. P. Pavlov school is, as is well known, displaying an invariable interest in psychology, especially in questions which are of some importance to physiology of higher nervous activity.

While developing the theory of conditioned reflexes Pavlov made many reports to congresses of psychologists and showed how important a role the new branch of physiology elaborated by him played in the materialist understanding of the complex phenomena of man's mental life. Of course, he gave particular emphasis to the importance of the conditioned reflex, he had discovered, for the physiological understanding of the theory of associations in psychology. It was on this question that he intended to report at the International Congress of Psychologists in Madrid in 1936.

The theory of higher nervous activity supplemented by the theory of interaction between the first and second signal systems made it possible to go still deeper into the complex processes of higher nervous activity which is specifically human, i.e., higher nervous activity revealed through speech and thinking. However, the more a physiologist of higher nervous activity studies the phenomena of man's mental activity, the more he is persuaded that the concept of the conditioned reflex, as a universal physiologic concept, must continue to acquire new facts which will bring it closer to purely psychological concepts. On the other hand, psychology armed with all the achievements of modern physiology of the brain, especially the achievements in the field of higher nervous activity, must

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* Report to Conference on Psychology, July 1-6, 1955.

reconsider its principal concepts from the point of view of these achievements. In other words, real success in constructing a materialist psychology can be reached only if both physiologists and psychologists direct their efforts towards a commonly formulated aim.

We are still far from such an organised and comprehensive elaboration of the main concepts of psychology, but joint conferences and congresses of psychologists and physiologists may help to solve this methodologically important problem.

Even if this is as yet the first stage in solving the problems which equally agitate the minds of physiologists and psychologists Pavlov's own contributions to such congresses show that they undoubtedly produce positive results. It is precisely because of these contributions that the main questions of physiology and psychology are now clearly defined and the theory of higher nervous activity has become the basis for elaborating a materialist psychology.

The very first question raised by us in this report to the Conference of Psychologists is: which of the many basic questions of physiology and psychology should form the subject of our report in order that the very aim of extensive connections between physiology and psychology may be justified?

CONCERNING THE DECISIVE ROLE OF AFFERENT SYSTEMS IN NERVOUS ACTIVITY

Our many years of studies (together with our associates) of the behaviour of animals have shown that the universal and decisive role of the afferent function of the organism in forming its higher adaptations, including mental acts, may serve as this basic question.

As a matter of fact, one could hardly find an adaptational act of an animal or man, in which the role of afferent impulses caused by the stimulatory agents of the external environment does not come to the foreground. Entering into the most diverse combinations the afferent impulses exercise continuous control over what the central nervous system must do at the given moment and what pattern of working excitations must form in the given external situation in order that the animal may most advantageously adapt itself to it.

This general role of the afferent function was many times and very clearly formulated by Pavlov, beginning in 1911 when he set forth his ideas about the food centre.

It was already then that his opinion of the decisive role of the afferent part of the central nervous system took shape and was subsequently repeatedly given expression. In 1911 he wrote:

"I think that the main centre of gravity of nervous activity is precisely in the receiving part of the central station; herein lies the basis of progress of the central nervous system effected by the brain, the cerebral hemispheres; here is the main organ of the most perfect equilibration of the external world possessed by animal organisms, whereas the centrifugal part is merely executory" (12).

Subsequently he invariably adhered to this point of view and considered all the physical material of higher nervous activity in accordance with it. We may therefore dispense with his numerous statements on the subject. However, the last Pavlovian formulation must necessarily be quoted because it extends this idea and because it will serve as the point of departure for our further investigations in this field.

After examining various problems of higher nervous activity Pavlov wrote:

"If we divide the entire central nervous system only in two halves—afferent and efferent—I should regard the cerebral cortex as an isolated afferent part. Only higher analysis and synthesis of the received stimuli take place in this part; from here *ready combinations of excitations and inhibitions* (Author's emphasis) are directed to the efferent part. In other words, only the afferent part is the active, so to speak, creative part, while the efferent part is only passive, executory" (14).

Somewhat later Pavlov pointed out still more definitely that the existence of afferent impulses is a *sine qua non* of the regulatory influence of the central nervous system on the peripheral organs.

Thus we see that in Pavlov's conception of the integral activity of the organism the afferent part of the nervous system, i.e., the *presence of constant afferent impulses from the periphery*, played the leading role. It is interesting that comparative quantitative morphological studies of the

nerve fibres of the posterior and anterior roots showed that there are always 3-5 times as many sensory fibres as there are motor fibres. This circumstance once more emphasises the universal importance of the function of afferent fibres.

However, the recognition of the universal importance of the afferent part of the central nervous system gives rise to several problems.

In the first place we discover a clear discrepancy between this conception and Descartes' reflex theory. To be sure, what role does Descartes ascribe to the afferent part of the central nervous system? According to the generally accepted scheme of the reflex arc, an afferent impulse always plays the role of only a starting stimulus, an "impetus". This stimulus may be more complex or less complex, but, according to the very idea of the "reflex arc", it is necessarily only an initial impulse to the development of a particular reflex act. Thus the development of a reflex act, which always expediently adapts the organism to the surroundings, requires, according to Descartes' conception, only an afferent stimulus and this essentially limits the role of the afferent system in forming the adaptive acts of animals and man.

Hence the clear discrepancy between Descartes' conception and Pavlov's formulations which were quoted above and according to which the decisive role in forming "combinations of excitations and inhibitions" is ascribed to the afferent system.

What is the essence of this contradiction? To begin with, the initial reflex scheme suggested by Descartes ("reflex arc") proved clearly inadequate in explaining the various facts obtained in the studies of the physiology of the animal's adaptive behaviour, especially in Pavlov's school.

By introducing into science the concept of an *external stimulus* which conditions the animal's adaptation to the external world, Descartes made a great contribution to the progress of materialist knowledge about man. Instead of all sorts of "spontaneous" and "prime" causes he attached the greatest importance to the material action of external agents on the nervous system of animals and man, thereby establishing a *deterministic* dependence of the behaviour of animals on changes in the external environment.

This part of Descartes' reflex theory was accepted by Pavlov who considered it "scientific", since it completely meets the requirements of the law of causality in the life of organisms.

But, having established the importance of the initial external stimulus for the animal's reflex responses, Descartes completely ignored the question as to why the animal's response is expedient. Why does a stimulus excite such a combination of central neural elements which necessarily manifest themselves on the periphery precisely in the given form of working efforts and not in another? These questions never occurred to Descartes; nor did he ever consider the question as to how the organism corrects the error if the reflex response did not at once produce an adaptive effect.

As a philosophical dualist Descartes left the question of the expedience of the reflex response to the "higher mind" and thereby for many years determined the fate of the studies of the complex adaptational acts of animals and man.

It may without any exaggeration be said that all through its pre-Pavlovian period of development the physiology of the nervous system endeavoured to deepen and render precise the analysis of the processes which constitute the "reflex arc" and neved tried to interpret physiologically the very fact of *expedience* of the reflex response. By introducing the *factor of reinforcement* into the process of acquisition of new reflex acts—conditioned reflexes—Pavlov radically altered the fate of studying the complex adaptational acts of animals.

It is this fact that reconciles the contradiction which arose in connection with Pavlov's high appraisal of the role of afferent impulsations in forming complex acts of behaviour.

The large number of investigations conducted by our associates over a period of 25 years has convinced us that the reconciliation of this contradiction must be sought not at the initial part of the "reflex arc", the stimulus, but at the other end of the reflex, i.e., in the very *reflex act*. It is to this that all that Pavlov said about the decisive role of the afferent part of the central nervous system refers; it is precisely here that the complex adjustment of the reflex act to the interests of the whole organism, i.e., all that actually deserves the epithet "creative", takes place.

Descartes' reflex theory assumes that the reflex response of the organism is expedient from the very outset and that its suitability to the given external conditions is taken for granted. Owing to this, all of physiology's attention has for many years been directed towards *ready*, earlier-formed reflex acts. However, the inappropriateness of the old ideas about the complexity of the animal's adaptational behaviour came particularly to the fore and became clear with the beginning of the *studies of the very process of formation or elaboration of new reflex responses necessarily requiring a preparation of the reflex by means of the reinforcement method* which, as is well known, forms the very essence of the conditioned reflex. Similarly the inadequacy of the "classical" reflex theory became particularly evident in the experiments where the animal *by way of compensation for the impaired functions* had to perform before the experimenter's eyes entirely new reflex acts which adequately adapt it to new conditions of life. This will be the subject of discussion in the next part of our report.

THEORY OF RETURN AFFERENTATION

Since 1930 our laboratory has been continuously studying the mechanisms of compensation for impaired functions of the organism. This fascinating problem, in addition to its enormous theoretical importance, also enables us to understand all the adjustment acts of the affected organism, which form the "physiologic measure" taken by the organism against the disease and bring its functional peculiarities into line with the new conditions. In this sense we have made an extensive study of the compensatory adjustments arising in cases of impairment of the animal's motor functions as a result of various special operations, especially as the result of cross anastomosis of nerve trunks (4).

The disturbances in motor activity are compensated for, as is well known, after a number of stages in which the animal resorts to various means which replace the impaired function and enable it to obtain the appropriate adaptive effect. If the impairment is not too large, the function is re-established more or less perfectly. The entire process of restoration usually involves an enormous variety of

attempts at correcting the defect by using all groups of the animal's muscles.

Our direct experiments have shown that this process of compensation operates more slowly if the extremity whose function, impaired as the result of cross anastomosis of nerves, is deafferented beforehand or if the corresponding cortical zone is removed after establishment of compensation (6). This decisive role of afferent impulses from the periphery in the process of compensation was particularly clear in the experiment performed by E. A. Asratyan who completely removed the cerebral cortex. Under these conditions the compensatory process was either entirely impossible or very limited (7).

In this report we intended to deal with the whole problem of compensation of functions, but this would have led us too far astray. It is important to show that it was precisely the elaboration of this problem that for the *first time* suggested to us the inadequacy of explaining the process of compensation only on the basis of Descartes' scheme of the "reflex arc". This work required that we formulate an additional link of the reflex in the form of a *continuously acting* return afferentation.

In order thoroughly to investigate the concrete mechanisms which gradually lead to compensation for the impaired functions we raised the following three questions:

1) Can the central nervous system *initiate* the compensatory process without a signal from the periphery concerning the defect of the function and by means of what concrete afferent impulses is this signal conveyed?

2) Since all of the animal's attempts to compensate for the defect are oriented in the direction precisely of *compensating for the defect* the question arises: what concrete physiologic mechanisms determine the *direction* of the chain of compensatory adjustments toward compensation for the defect?

3) On the basis of what information does the central nervous system determine the *end* of the adaptational reactions, i.e., the restoration of functions; on the basis of what mechanisms does it discontinue further attempts to restore the functions and consolidate the newly formed system of central interrelations?

Suffice it carefully to analyse these three questions to see that without a more or less satisfactory answer to

these questions there can be no finished theory of compensation of functions. Only by answering these questions will we be able to build a deterministically linked chain of physiologic processes guiding the compensation from the moment of infliction of the defect to the moment of restoration of the function.

For a more detailed acquaintance with the elaboration of these three questions on models of impaired functions we refer the readers to our publications on this subject (5).

Let us dwell on the general regularities which inevitably follow from our many years of research into this subject.

In the first place it must be pointed out that not one reflex act which arises in response to a signal about the defect of a function can lead to any positive effect without immediate return afferentation which is an index of the sufficient or insufficient effectiveness of the performed reflex act.

Without this return signal about the degree of success of the first reflex responses of the central nervous system there can be no restoration of functions.

To begin with, we should like to define the term "return afferentation" suggested by us for the purpose of explaining the continuous correction of the process of compensation from the periphery. This term implies that the afferent signalling arising as the result of reflex action is directed precisely towards the complex of processes in the central nervous system, which conditioned the given action at the periphery. This is in the true sense of the word a "return" afferentation since it is aimed in a direction opposite to the produced effector excitation, but returns to the points of departure of this excitation. Schematically, these interactions may be represented as follows (Fig. 1).

A natural question arises: how widespread can these interactions be in the direction of normal reflex activity of animals and man?

By way of example we shall first of all point out the importance of the *factor of reinforcement* in the elaboration of conditioned reflexes of various biological significance. By introducing the very concept of *reinforcement* Pavlov quite obviously thought of the opposite direction of the afferent impulses which arise from the action of

an unconditioned stimulus on various combinations of receptor formations.

As a matter of fact, the very meaning of this expression suggests that it is possible to "reinforce" only that which is already taking place, exists and is the addressee of the reinforcement. As we shall see below, such a preceding formation is the conditioned excitation in the cerebral cortex or, to be exact, excitation of the cortical represen-

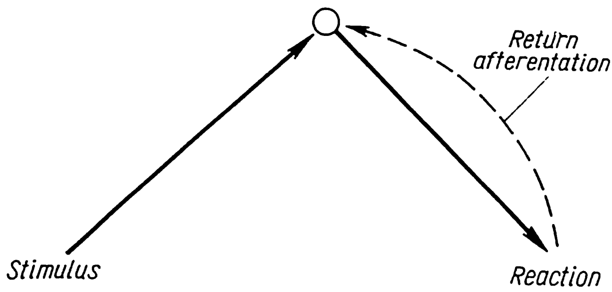

Fig. 1.

tation of the unconditioned centre evoked by the conditioned stimulus.

Thus both the elaboration and the subsequent existence of the conditioned reflex are possible only through its continuous reinforcement by an unconditioned reflex or through continuous return afferentation. Reinforcement of a conditioned reflex is, as is well known, a biological factor which determines the expedience of adaptation of the organism to the given external conditions. Reinforcement is a factor which corrects this adaptation and, consequently, is as much an inalienable part of the conditioned reflex, and in case of successive compensatory adjustments is, like any return afferentation, an inalienable part of the produced reflex act.

From this point of view it would be correct to point out that by introducing the *factor of reinforcement* into the process of elaborating *new* reflex responses in the organism Pavlov reflected the universal regularity in the life of all organisms, the regularity which directs all reflex activity under any conditions of natural existence of organisms. It is this regularity that we have named return

afferentation and imparted a corrective and reinforcing action to it. Today we can hardly conceive of any reflex act of an intact animal ending only with the effector link of the "reflex arc" as is required by the traditional Cartesian scheme.

But supposing there is such a reflex act or one is pointed out to us. According to the idea of reflex activity this act must either produce a successful adaptive effect or fail to produce it. In the former case the given reflex act *ends* and the animal must pass on to the next link of its behaviour; in the latter case it makes a number of new attempts to produce the positive effect it failed to produce by the first act.

But how can the animal's nervous system discover the difference between these two possible effects of the reflex act?

We might say that animals do not have to discover this difference. But such animals would at once be doomed to extinction. Consequently, there can hardly be any doubt that during each reflex act an animal immediately (!) receives a return signal as to whether or not the act has produced the adaptive effect. Only under this condition, i.e., with the existence of continuous return afferentation which, like an echo, accompanies every reflex act can all natural behaviour acts of the intact animal arise, cease and change to other acts, making up as a whole an organised chain of expedient adaptations to surrounding conditions.*

Several questions requiring more accurate definition arise in connection with the aforesaid ideas about the necessity of return afferentation.

In the first place it is necessary to determine the *composition* of return afferent signalling. In the beginning we did not determine the detailed composition of return afferentation and confined ourselves to pointing out in general that it arises from *organs of action*. Since such a general expression may not entirely correctly orient investigators in discussing this important problem I shall now venture a more precise formulation of this question.

Return afferentation must, by its very implication, very closely reflect the degree of success of the given reflex act

* In this case, as in all other cases, the concept of "expedience" is used by us in a broad biological sense, as was done by Pavlov.

and, consequently, its composition must depend directly on how complex the given act is and on what receptor surfaces the result of this act may be determined. Usually all our acts have many-sided afferentation. Figuratively speaking, every reflex act fires a whole round of afferentations at the central nervous system, the afferentations differing in strength, localisation, time of origination and speed of propagation through the central nervous system. In other words, in each individual case we have a peculiar afferent integral which to the finest details reflects the adaptive effect of the given reflex act.

When we pick up a knife or fork this action immediately terminates in a complex of tactile, thermal, visual and kinesthetic afferent stimuli which signal the end and success of the given reflex act.

It should be remembered, however, that with a large number of various return afferentations and some reflex action some of the afferentations are eliminated and the leading afferentation comes to the foreground, i.e., the afferent impulses which acquire the decisive identifying significance. But in the case of elimination of the leading afferentation other receptor surfaces, which did not formerly play a decisive role, come to the fore.

In more complex acts (for example, entrance into a room) the return afferentation which signals the correctness of the given act may include many afferent impulses, for instance, the appearance of the room and its particulars, temperature, olfactory and, lastly, kinesthetic afferentations.

In connection with the evaluation of the composition of the return afferentations the question also arises as to how widely it is possible to use the term "reinforcement" for various kinds of reflex acts. All our actions are by their very nature continuous and chainlike. Every link of this chain, ending in a return afferentation typical of it, passes on to the next link.

But a correct succession of these links can be guaranteed only if each link receives as a "reinforcement" an adequate return afferentation.

Consequently, the concept of "reinforcement" may be with good reason applied to any fractional stage of adaptation which has received appropriate return afferentation.

The terminal stage of all compensatory adjustments or

of any long series of reflex acts is the production of the main adaptive effect. Like all other stages of adaptation this terminal stage also has its return afferentation which, however, is characterised by certain peculiarities. It does not stimulate the nervous system to form increasingly new reflex acts, but, on the contrary, *arrests* further attempts at organising new reflex acts and *consolidates* this last combination of excitations in the brain centres, the combination which has produced a successful adaptive effect on the periphery.

At one time we named this last return afferentation the *sanctioning afferentation* since it really "sanctions" the last system of interrelations formed in the nerve centres.

Coming back to all we said earlier in this part of the article we may conclude that the afferent phenomena which come into play at the end of a reflex act are so diverse and so important to the development of the animal's expedient adaptations and, especially, to compensation for the defects of functions that they may with good reason be classified as a special category of *return afferentations*.

Return afferentations, as a universal phenomenon in the behaviour of animals, are a property of an *integral* animal, a phenomenon of its natural behaviour. Naturally, they cannot take place or lead to any adaptive effect under conditions of vivisection. It is precisely to this circumstance that we owe the paradoxical fact that the continuous corrective action of the return afferentations has never been noticed despite the 300 years of development of Descartes' reflex theory. Vivisection which has produced abundant *analytical* results has entirely eliminated the very possibility of discovering return afferentations and, consequently, of describing the complete architecture of nervous processes in the adaptational act.

But after the studies of the different forms of return afferentations it has now become perfectly clear that the generally-accepted present-day concept of the *chain reflex* is inadequate and requires serious modification.

According to current conceptions, the chain reflex consists in the fact that the "end of one action serves as the beginning of another". We saw, however, that the end of an action can never serve as the beginning of another action. The end of an action in one link is the source of return afferentation which is directed to the centres of the just developed reflex

and only after that, and *depending on the results which this return afferentation will have in the nerve centres, will the next stage of the chain reflex begin to form* (Fig. 2).

Fig. 2 is a comparative representation of a chain reflex, as it is usually conceived (A), and a chain of return afferentations, as it occurs to us on the basis of extending

Comparison of the chain reflex with the chain of return afferentations

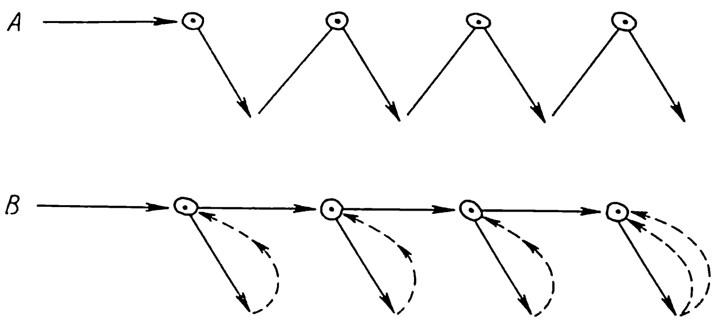

Fig. 2.

Descartes' reflex scheme (B). Let us assume that during the development of a chain reflex in accordance with the old conceptions (A) the reflex act happened to be incorrect at one of the links of this reflex and we shall immediately see that this scheme cannot be applied to the real conditions of the animal's life because the *incorrectness could not possibly be corrected.*

The development of the theory of return afferentation necessarily had to raise the following question: how is the return afferentation related to the "classical" reflex arc, to what extent does it supplement it, and can return afferentation be the *fourth link* of the reflex? As a matter of fact, return afferentation has as much reason for becoming one of the links of the reflex as its already known links. It is, as we see, absolutely necessary for the purpose of effecting an expedient adaptation and it actually corrects the imperfection in the activity of the first three links; it is as constant in each reflex act as the other links

and, lastly, it has a very definite physiologic and structural content. From all of the aforesaid we cannot raise any serious objections to the return afferentation becoming the supplementary or fourth link of the reflex. This transformation of the Cartesian reflex scheme removes a long series of contradictions which have now accumulated and at the same time offers extensive opportunities for studying and explaining the complex forms of behaviour of animals and man under the natural conditions of their existence.

It should be noted that in recent years investigators outside the U.S.S.R. have closely approached the aforesaid concepts, often even in very similar expressions.

Suffice it to point out the statements made by Adrian who in one of his last public lectures (commemorating Jackson) tried to gain an insight into the plastic adjustments of animals to the surrounding conditions. In summing up the modern achievements in the physiology of the brain he hesitates before the complex forms of animal adaptation. Cautiously approaching the subject he writes that it is possible that expedient movement is guided by its results (1).

Various investigators formed similar conjectures at the International Congress devoted to "Principles of Complex Organisation of the Nervous System" (2). Wagner also comes close to these problems in his monograph "Problems and Samples of Biological Regulation" where he develops a "servotheory" and on its basis tries to delve into the nature of adaptive behaviour (15). But cybernetics has come particularly close to this question by making use of the concept of "freedback" to regulate the correctness and expedience of the work of both the machine and the human organism. All these statements were made much later than our first publications on the given question and, forming general conjectures, were very far from revealing the physiologic mechanisms. Nevertheless, this circumstance once more emphasises the need for further elaboration of the aforesaid conception formed as a result of a number of investigations conducted by scientists.

We have left open the second of the aforesaid questions, namely, what *guides* all searches of the adaptational acts under conditions of compensation for impaired functions? This question is most intimately connected with the further development of our ideas about the physiologic prin-

ciples of the expedient character of reflex acts and will, therefore, be given special consideration in the next part of this article.

THEORY OF THE ACCEPTOR OF ACTION

When we began elaborating the concept of sanctioning afferentation, as the concluding form of return afferentation, we were faced with questions which gradually led us to the discovery of a special central afferent apparatus of which we had had no idea before.

If a whole series of return afferentations necessarily accompanies the entire series of compensatory adjustments, including restoration of function, the following question inevitably arises: why does the central nervous system terminate the entire series of compensatory adjustments and the organism stops precisely at the last attempt at compensation? Figuratively speaking, how and by what signs does the organism judge that precisely this last, i.e., sanctioning afferentation, is really the one which meets the necessary requirements of its adaptation to the external world?

Since this question plays a very important part in understanding the characteristics of the afferent apparatus of reflex activity we must define it still more precisely. Let us designate the complexes of return afferentations which accompany the series of successive adjustments by appropriate symbols. Let the first inadequate afferentation be $a + b + k$, the second—$a + k + l$, the third—$a + k + p$ and, lastly, the sanctioning afferentation—$a + k + m + t$. Adhering to deterministic physiologic positions we must ask ourselves the question: by what methods does the central nervous system determine the difference between the various links of this chain of return afferentations? In other words, *how does the animal "know" that precisely the last afferent complex* ($a + k + m + t$) *is the information on the finally restored effect or generally on the production of the adaptive effect*? If we adhere to strictly deterministic positions, none of the material at the disposal of our neurophysiology can give us an answer to this question. As a matter of fact, for the animal's central nervous system all return afferentations, including the sanctioning afferentation, are but complexes of afferent

impulsations and, from the usual point of view, there are no apparent reasons why one of them should *stimulate* the central nervous system to a further mobilisation of adaptational reflex acts, while another should, on the contrary, *stop* the adaptational acts.

Suppose we wanted to take a cup from a table on which there are many dishes, but as we reached out for it we absent-mindedly grasped the handle of a pitcher. As we all know from personal experience, we usually correct an accidental mistake at once; in this case we would replace the pitcher and our hand would find the requisite cup.

On what physiologic basis did we notice our mistake and correct it?

The appearance of the pitcher and the grasping of its handle, as well as the appearance of the cup and the grasping of its handle, are only an aggregate of return afferent impulses differing in but a few of their components. Why then did we prefer precisely the latter return afferentation, as the final, i.e., sanctioning afferentation?

Such facts often occur in our life; they manifest themselves at each step, in each act of our multifarious behaviour.

The last example makes it clear that only that afferentation stops further reflex acts which corresponds to the *intention* that generated the reflex act, or, speaking physiologically, the return afferentation must correspond to *some ready complex of excitations which had arisen before the reflex act itself took form.*

As a result of such reasoning we could not escape the conclusion that this ready complex of excitations, which precedes the reflex act, must be some sort of an afferent "control" apparatus that determines *to what extent the given return afferentation which has come to the central nervous system corresponds to it.*

We devoted special attention to the elaboration of this question on the example of the conditioned food reflex and its return afferentation—reinforcement with food.

It was long ago noted that the conditioned excitation which arises in the cerebral cortex in response to the application of the given conditioned stimulus is not an excitation that by its quality should be common to all conditioned signals. The aggregate of external signs of the behaviour has, on the contrary, shown that the character

of this conditioned excitation is directly dependent on the quality of the reinforcing factor. The most vivid example of this dependence is the biological quality of the conditioned reaction in response to the conditioned stimuli reinforced by *food and electric current*.

In a more demonstrative form this dependence is seen even within the limits of the selfsame unconditioned reinforcement. For example, in Pavlov's laboratory it was long ago shown that the chemical composition of conditioned-reflex saliva precisely corresponds to the quality of the food reinforcement and, consequently, to the character of its salivatory action.

It is this exact coincidence of the quality of unconditioned and conditioned excitation that has given rise to theories of "substitution", "anticipation", etc., which are but verbal designations of the generally known phenomenon, but which do not bring us even a step closer to revealing its physiologic nature (9).

On the basis of what concrete physiologic mechanisms does *conditioned effector excitation* in the form of secretion and general alimentary excitation arising in response to the given conditioned stimulus prove more or less appropriate to the effector excitations which must *subsequently* also arise in response to the reinforcing factor? This question is still unsettled and if it is to be rendered more precise, it may be asked as follows: does the conditioned excitation evoked by the conditioned stimulus in the corresponding analyser pass directly to the *effector pathways* of the unconditioned stimulus or does it first reproduce its afferent part concentrated, as is well known, in the cortical representation of the unconditioned reflex? (13).

The following simple scheme may be suggested to elucidate this second question.

The scheme shows that by assuming that the conditioned stimulation spreads from the area of the corresponding analyser directly to the centre of the unconditioned reflex we come back to Pavlov's very first assumption of the coupling of the conditioned reflex arc (I in Fig. 3). As is well known, numerous subsequent experimental data persuaded Pavlov to recognise cortical localisation of both links coupling the conditioned connection. He assumed that it was established between the cells of the correspond-

ing analyser and the cells of the cortical representation of the unconditioned stimulus, which fully agreed with all the factual materials in the possession of the laboratories of Pavlov, as well as those of his pupils, and is now therefore generally recognised. But from this proposition it follows that the conditioned excitation of the corresponding analyser may spread to the unconditioned food centre *only through its cortical representation* (II-b).

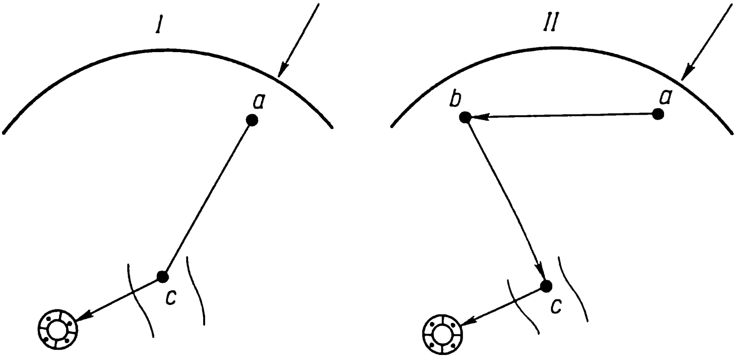

Fig. 3.

Despite the fact that this proposition fully agrees with our ideas about the physiologic architecture of the conditioned reflex and is now commonly accepted, no special attention has as yet been devoted to the physiologic consequences which inevitably ensue from the acceptance of this proposition.

Indeed, what is the physiologic essence of the "cortical representation of the unconditioned centre"? From the very meaning of unconditioned reinforcement, as an afferent stimulation, it follows that this "representation" must be of an *afferent character*, and this fully agrees with Pavlov's point of view of the cortex as an "isolated afferent part" of the central nervous system (see above).

The experiments of our associate I. I. Laptev, who used the oscillographic method, show that the unconditioned stimulus itself evokes quite a complex afferent discharge. The tactile, temperature and chemical receptors of the tongue are stimulated in a definite succession, the specific

streams of impulses reaching the different parts of the cerebral cortex at different rates of speed.

This makes it clear that the cortical representation of the unconditioned stimulus is not some definite "focus" or "point" in the cerebral cortex, but a system of afferent cells integrated in a single whole (11).

But then, considering all these data, we must accept the following very important proposition: *every conditioned excitation proceeds through a corresponding analyser to the system of afferent connections of the cortical representation of the unconditioned centre, which system was repeatedly excited by the unconditioned stimulus in the past, and several seconds after the conditioned excitation reaches it will again be stimulated by the same unconditioned stimulus*. In other words, during each test of the conditioned stimulus the group or system of cortical cells, which under the action of the conditioned stimulus reproduces the gustatory qualities of the unconditioned stimulus, *becomes excited several seconds before it is reached by the new unconditioned excitation ("reinforcement").*

We must for one moment imagine the peculiar correlation of the nervous excitations established in the cortical apparatus of the conditioned reaction when, as a result of the unconditioned reinforcement, the apparatus is reached by streams of various, but always specific, afferent excitations ("return afferentation"), remembering that the quality of these excitations is directly dependent on the peculiarity of the stimulatory action of the given reinforcing agent on the visual, olfactory and gustatory receptors.

This succession in the development of cortical processes over a period of 15 seconds of the isolated action of the conditioned stimulus may be pictured according to phases, as shown in Fig. 4.

Let us assume that all the conditioned stimuli in the given experimental animal are reinforced all the year round by 20 g of ground dry bread. Having passed through all the sensory pathways this stimulation excites definite afferent cells *B* (tactile, temperature, chemical) in the cerebral cortex. The system of interrelations between these cells will subsequently form the afferent cortical representation of the unconditioned centre.

Three successive stages of manifestation of the conditioned reaction

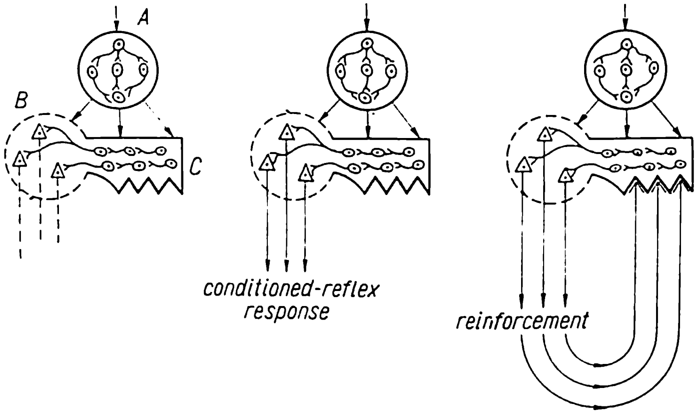

Fig. 4.

As a result of long training of the conditioned reflex, such correlations are formed in the cerebral cortex, i.e., in the cortical representation of the unconditioned centre, that each new application of the conditioned stimulus *simultaneously* with the effector apparatus of the conditioned reaction (secretion, movement, respiration, etc.) *also excites this additional afferent apparatus which precisely reproduces the qualitative peculiarities of the always used food reinforcement.* As in the case of compensation, this cortical afferent apparatus of conditioned excitation proves to be a sort of "control apparatus" which manifests its action several seconds after the beginning of the action of the conditioned stimulus, i.e., *when the unconditioned food stimulus already begins its action.*

At the moment the return afferent impulses from the unconditioned stimulus reach the cortex the animal's behaviour will be usual and stable only if the unconditioned excitation exactly corresponds in visual, olfactory and gustatory qualities to the *prepared afferent excitation* which was called to life by the conditioned stimulus several seconds before the reinforcement. The final correlations in the afferent apparatus are as they are shown in Fig. 4 (third phase).

We believe that this scheme is fundamental and may

be used to explain any form of elaborated adaptational behaviour.

As the scheme shows, return afferentation arising from the action of the unconditioned stimulus must precisely correspond to the additional complex of afferent excitations which forms part of the conditioned excitation. In cases of complete correspondence of these two excitations the animal's behaviour remains normal, i.e., the animal's food excitation is "satisfied", which fully corresponds to the formerly elaborated signalling correlations between the conditioned stimulus and the reinforcement. From this point of view the additional afferent apparatus of the conditioned reflex must be regarded as an apparatus which effects the final evaluation of the *adequacy or inadequacy of the reinforcement or the adaptive effect* that followed the signalling stimulus.

The idea of the existence of such a physiologic apparatus in the cerebral cortex (of "sanctioning afferentation") occurred to us for the first time about 25 years ago (4). Special experiments were needed, however, to make sure of the concrete physiologic properties of this apparatus, and for this purpose we undertook a series of special experiments.

In conducting these experiments we reasoned as follows: if the prepared conditioned excitation of the afferent cells in the cortical representation of the unconditioned centre precisely reflects the properties of the *future return unconditioned excitation* and the normally elaborated behaviour of animals is based on this adequacy, this behaviour must necessarily change, providing an urgent substitution is made for the unconditioned stimulus. Owing to this substitution the outstripping conditioned excitation in the additional afferent apparatus would be of one quality (on the basis of the former reinforcements), whereas the unconditioned stimulus would suddenly (!) be of another quality and, consequently, the return afferentation reaching the cerebral cortex from this stimulus would, by the composition of its nervous impulses, fail to correspond to the prepared conditioned excitation. How, concretely, will the animal behave in this case?

Methodologically this project was carried out in our laboratory (3) on the basis of a bilateral food reinforce-

ment which makes it possible to reveal these peculiarities of higher nervous activity.

The experiment was conducted as follows. Only two conditioned secretory-motor reflexes were elaborated in the animal: to the tone "la", with reinforcement on the right side, and the tone "fa", with reinforcement on the left side of the stand. Both reflexes were reinforced by 20 g of dry bread and were sufficiently well consolidated. After a short latent period the animal passed to the corresponding side of the stand where it waited for the unconditioned stimulus. At this stage of experiment the animal no longer had any erroneous motor reactions.

In the beginning of an experimental day dry meat was placed on one of the plates on the left side, and thus, against the background of the usual reinforcement by dry bread, at one of the regular applications of the tone "fa" the animal had to receive a meat reinforcement. On the basis of the aforementioned peculiarities of the afferent apparatus of conditioned excitation we must assume that for a certain moment the new unconditioned stimulations which by *their visual, olfactory and gustatory qualities do not coincide with the already started conditioned excitation* must at first lead to a failure of the two excitations to coincide and then to the development of the orienting-exploratory reaction. This latter must be the more pronounced, the greater the lack of coincidence between the prepared conditioned afferent excitations and available afferent excitations from the actual unconditioned stimulus.

To be sure, such substitution for the unconditioned stimulus usually gives rise to the orienting-exploratory reaction which, depending on the strength of the stimulatory action of the additionally applied unconditioned stimulus, changes to an active food reaction (on replacement of dry bread by meat) or to an inhibition of the food reaction and even a refusal to eat (on replacement of meat by dry bread).

The foregoing experiment enabled us to observe both forms of the reaction, particularly clearly the second form which we shall describe in greater detail in view of its importance.

When the animal is additionally given meat, which it devours after a brief orienting-exploratory reaction, its

usual stereotypical behaviour under the same conditions of the experiment sharply changes.

To begin with, it does not, as usual, leave the feeding-trough and does not go to the middle of the stand, but remains sitting near the feeding-trough from which it was just given the extra meat reinforcement. Subsequently, for several days the animal's behaviour has a very definite physiologic content. Coming into the experimental room and jumping into the stand it immediately goes to the feeding-trough on the left, i. e., *to the one where it once received meat.* Here the animal manifests an emphatic exploratory reaction by intensively smelling the feeding-trough.

The subsequent behaviour of this animal enables us to understand the physiologic content of this behaviour.

As soon as the conditioned stimulus is given, *regardless of the side of the stand with which this stimulus is conditionally connected,* the animal rushes to the *left* feeding-trough and stands there until fed. This reaction arises upon application of both the tone "fa" (left side) and the tone "la" (right side). Here we have emphasised *dominance* of the entire system of excitations which determines the animal's reaction to the left side and which was strengthened by reinforcement with meat. The consumption of the meat clearly produced a dominance of the entire "left reaction". The very fact of producing such persistent dominance by one extra feeding with meat is of considerable interest to the characterisation of the correlation between the conditioned and unconditioned reflexes, but at the present we are interested in another circumstance.

As we have already stated, during this period of work, when we used the tone "la" (for the right side), the animal ran to the *left side* and stood there until fed, but as soon as the animal was given a bowl with ordinary dry bread *it turned away and refused to eat.*

The food excitation which had at first increased subsequently diminished, the conditioned secretion decreased and at times disappeared altogether. In such cases the dog sank into a clearly neurotic state.

We shall try to picture the aggregate of physiologic correlations according to which such a reaction could have taken place.

The very fact of a motor reaction to the left, "meat" side 20 days after a single reinforcement with meat shows that *one* extra reinforcement with meat produced a dominant state in the definite system of relations for all the 20 days. This circumstance would alone suffice to draw the conclusion about the quality of the acceptor of action which is prepared during the given conditioned excitation: by its afferent qualities it must exactly correspond to the stimulation of the animal's analysers with *meat*. The animal's refusal to eat *dry bread* is a direct confirmation of this assumption. Thus the presence of a motor reaction with a clear dominance "meatward" and the subsequent refusal to eat dry bread attest that the lack of correspondence between the supplementary afferent complex of conditioned excitation and the return afferentation from the real unconditioned reinforcement is a most important factor determining the behaviour and state of the animal.

As a matter of fact, all forms of elaborated conditioned reflex acts are performed with the necessary interaction of the afferent apparatus of the conditioned reflex and the return excitations from the reinforcing agents. If these excitations are commensurate with each other, the animal's behaviour act is sanctioned and consolidated. But, if the return excitation is not commensurate with the excitations of this afferent apparatus, an orienting-exploratory reaction immediately arises, this reaction *mobilising a maximum* of the afferent function of the cerebral cortex (by incorporating and intensifying the excitations of all the analysers) and leading to organisation of new complexes of afferent excitations. As the result of this, increasingly more perfect peripheral efforts are made. These "trials" are repeated until the return afferentation from one of the actions proves fully commensurate with the complex of afferent excitations which arose *at the very outset of the given behaviour act*.

Going back to the experiments with the substitution for the unconditioned reinforcement we must add that the necessity for *correspondence* between these two excitations becomes particularly evident where the animal manifests an emphatic orienting-exploratory reaction and *even refuses to eat meat,* if it is specially substituted for the usual reinforcement with dry bread (I. A. Zachinyayeva's observation).

The question is: what was wrong? Why couldn't the animal eat the meat as simply and immediately as it had theretofore eaten the dry bread? It is clear that the animal could react the way it did only *because the meat did not correspond to something*. But what? Now we already know the mechanism of this lack of correspondence: the aggregate of the signs of meat (appearance, odour), as signs of the unconditioned stimulus, on reaching the cerebral cortex in the form of specific nervous impulses, proved incommensurate with the prepared afferent excitation which arose already in the very beginning of the action of the conditioned stimulus and fully corresponded to all the afferent signs of the dry bread used earlier. It follows that in the aforesaid form of experiment we disturbed the commensurate correlations which, after many reinforcements, had become established between the additional afferent complex of conditioned excitation and the return afferentation which always arose from the eating of dry bread.

In these experiments we established precisely that during the period of isolated action of the well-formed conditioned stimulation in the dog's cerebral cortex, there also arises, in addition to the processes determining the effectiveness of the conditioned reaction (secretion, respiration, movement, etc.), an additional complex of afferent traces of former reinforcements. *All of the animal's subsequent behaviour depends directly on the extent to which this additional afferent complex of the conditioned reflex corresponds to the stream of afferent impulses evoked by the reinforcing agent from the periphery.*

However, any substitution for or elimination of the conditioned reinforcements, i.e., *any dissociation between the additional afferent complex of conditioned excitation and the return afferent impulse from the unconditioned stimulus, primarily gives rise to the orienting-exploratory reaction* (Fig. 5). There are reasons to believe that an important role in determining this coincidence or lack of coincidence of the two excitations is played by the frontal parts of the cerebral cortex (data furnished by A. I. Shumilina, 1949).

Since the aforesaid experiments revealed a theretofore unknown peculiarity of higher nervous activity we had to give it some sort of designation (Fig. 5*a* and 5*b*).

The most characteristic physiologic feature of the additional afferent complex of conditioned excitation is its reception of the return afferent impulses arising as a result of reflex action, and the determination of the correspondence of these return afferentations to the prepared excitation, i.e., the animal's past experience. That is why we decided on the expression "acceptor of action" as the most suitable term to designate this cortical apparatus. It would be more appropriate and more precise to name

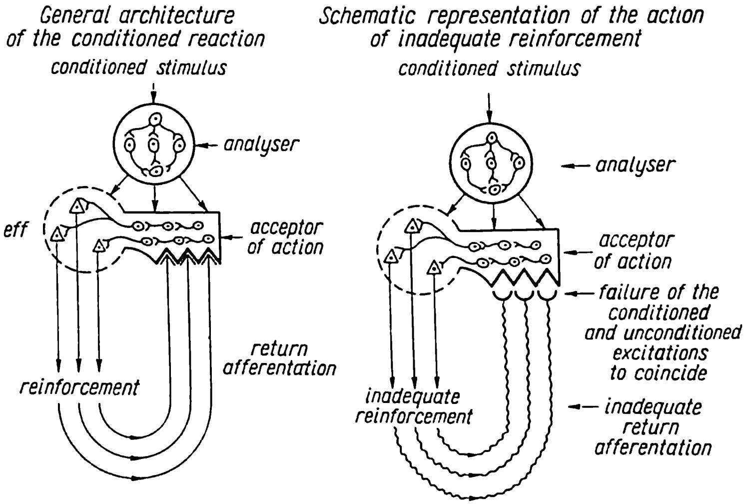

Fig. 5.

this apparatus the "acceptor of the afferent results of a performed reflex act", but for the sake of simplicity we preferred the abbreviated expression—"acceptor of action". The concept of "acceptor" precisely reflects the implication of all the experimental data obtained by us and our associates since 1930, because the Latin *acceptare* combines two connotations—*accept* and *approve*.

We are skipping the question as to how apt the term suggested by us is. At the present moment it is important to note that by this term we have designated a very real physiologic apparatus which performs the *function of evaluating by the cerebral cortex the results of any reflex act, any adaptational action of the intact animal*. Forming

under the influence of past actions and being part of any conditioned excitation and behaviour act the acceptor of action performs the decisive function of adaptational behaviour: *owing to the acceptor of action and on the basis of receiving various impulses from the periphery the degree of precision and adequacy of performed acts with regard to the initial motivating stimuli is determined.*

If, for example, a conditioned stimulus always reinforced by meat has acted on the nervous system of an animal, the acceptor of action forming already in the *beginning of the action* of the conditioned stimulus (Fig. 5), i.e., long before the reinforcement, then determines *to what extent the received reinforcement corresponds to the animal's former afferent experience.*

An example may also be taken from our daily life. If a person sitting in his study for some reason or other decides to go to the dining-room, at that very moment the total afferent complex of all signs and stimulations he received from the dining-room in the past (acceptor of action) is reproduced in his cerebral cortex. After entering the dining-room and receiving from it a definite sum of stimulations in the form of return afferentations, *which completely coincide with the acceptor of action formed earlier*, the person passes to the next link of his behaviour.

But suppose the person enters absent-mindedly not the dining-room, but the kitchen or the bath-room. The aggregate of all the external stimulations from the kitchen or bath-room atmosphere is such that upon reaching the cerebral cortex these stimulations *immediately reveal a lack of coincidence with the acceptor of action characteristic of the dining-room and formed in the cerebral cortex when the person was still in his study.* As a result of this dissociation between the prepared additional afferent complex and the return afferentations from the end of the inappropriate action an orienting-exploratory reaction immediately arises in the person and he *corrects his mistake,* i.e., brings the prepared afferent excitation into correspondence with the reinforcing action of the dining-room atmosphere as a whole.

From this it follows that the presence of an additional afferent complex during any of our actions is the only and universal factor which safeguards us against mistakes or enables us to correct the mistakes we have already

made. We do not as yet see any other possibility of explaining on a physiologic basis why the person who wishes to enter the dining-room, but by mistake enters the bathroom, *discovers* the error in his behaviour.

This regularity is so universal and is of such decisive importance to understanding the behaviour of animals and man that it could not, of course, have escaped the attention of the investigators who at different times and in different forms invariably felt a need for disclosing it.

In the first place it should be once more pointed out that the very fact of "reinforcement", which is of universal importance to the theory of higher nervous activity, is an expression of this regularity. It is precisely the supplementing of the reflex with reinforcement that the theory of conditioned reflexes has fundamentally altered Descartes' reflex theory.

Similarly the "law of effect" suggested by Thorndike in 1935 for a phenomenological evaluation of animal behaviour is essentially only an external expression of the foregoing physiologic regularity analysed by us. In this connection mention must also be made of Ikskül's statement (1929) concerning "ideas" in animals, which served as the basis for his idealist construction. Adrian's conjecture that an action is possibly "guided by its results" undoubtedly also refers to the same problem (1).

Cybernetics has made wide use of the idea of return regulations (feedback) in computers and other automatic devices. It goes without saying that the so-called "Charpentier's illusion" is a direct result of this regularity.

In the Soviet Union the closest approach to this problem has been made, on the one hand, by psychologists in their investigation of the so-called "sets" (D. N. Uznadze and his associates) and, on the other hand, by I. S. Beritov's physiological laboratory in its study of "idea" as a factor guiding the behaviour of animals (8). However, not one of the aforesaid trends made an attempt at interpreting this phenomenon physiologically.

We have abstained from the use of psychological designations of these peculiarities of higher nervous activity since the very beginning of our laboratory's work in this direction and have named this regulatory factor the "sanctioning afferentation"; as could be seen from the foregoing, this regularity proved completely subject to

physiologic interpretation without losing its synthetic role in the adaptational behaviour of animals.

A very close approach to our conception of conditioned excitation was also made in recent years by P. S. Kupalov without, however, revealing the physiologic mechanisms of the supplementary apparatus which regulates the expedient adaptation of animals to the external environment (10).

ROLE OF THE FOREGOING THEORY IN EXPLAINING CERTAIN PHYSIOLOGIC AND MENTAL PHENOMENA

The most effective aspect of the theoretical ideas about the architecture of the additional afferent apparatus of all reflex reactions is that they enable us to clarify and put physiologic content into the processes which have so far failed to be explained.

For example, we have already called attention to the question: why does the whole series of compensatory adjustments in cases of impairement of function always proceed in one definite direction, namely, toward restoration of function? What mechanisms guide the choice of reflex acts increasingly closer to restoration of functions? The adoption of the concept of the acceptor of action makes this whole process clear. Schematically, according to the various stages of adaptation, it is shown in Fig. 6.

Fig. 6 (I) shows the architecture of a *normal* reflex act, as it was described above. An external stimulus evokes in the cerebral cortex simultaneous excitation of all parts of the cortical apparatus of this act. The acceptor of action is shown, as on the preceding plates, in the form of an additional apparatus with connections commensurate with very definite return afferentation ("complemental connection").

The series of stages shown in Fig. 6 (II) represents the gradual evolution of adaptational behaviour after the infliction of a defect on function "A". The first stage (a) shows that under the action of the former external stimulus the former complex of central excitations, both of effector and of the acceptor of action, forms in the central nervous system. However, in view of the defect in peripheral action the produced reflex action is not adaptational and a new return afferentation therefore arises, but does not coincide

with the prepared acceptor of action. The lack of coincidence is symbolically shown by horizontal lines which do not pass into the acceptor of action. The most important result of this lack of coincidence is that the central nervous system mobilises all its resources and builds a *new* system of central excitations of an efferent character (b) *completely leaving* the acceptor of action *as it is* since the given stimulus may be a stimulus for a very definite

Successive stages of compensatory adjustments

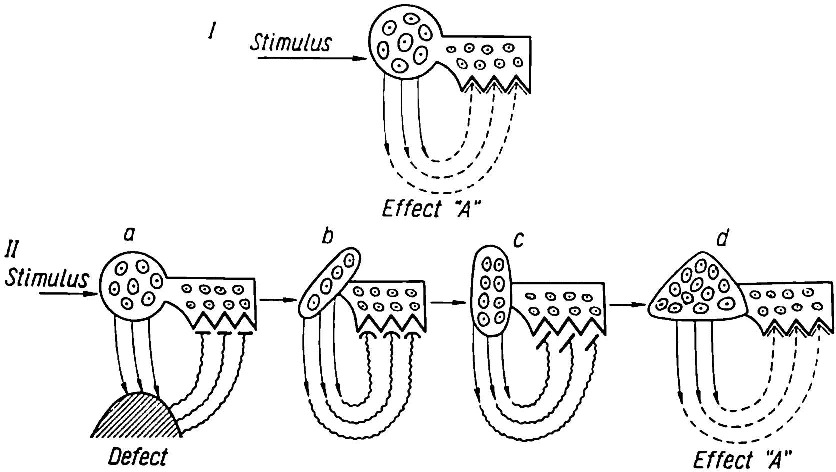

Fig. 6.

adaptational act. However, this second action also fails to produce the adaptive effect "A" with the result that the picture of central excitations is again reconstructed and a new adaptational action with a new form of return afferentation is created (c). Diagram II shows a series of such successive adjustments connected with formation each time of a new picture of central effector excitations. According to the diagram, only the last system of central excitations (d) has produced the adaptive effect "A" which has led to a coincidence of the return afferentation with the excitations of the acceptor of action.

Two circumstances in this diagram require special attention: 1) in case of compensation for a defect in function the end adaptive effect is, as a rule, produced by another

system of central effector excitations, differing from the normal, and 2) the acceptor of action connected with the peculiarities of the adaptive effect "A" *remains the same all through the compensatory adjustments*. It is this last circumstance that directs the whole series of compensatory adjustments. The action is "sanctioned" only provided the return afferentation from it proves commensurate with the excitations of the acceptor of action.

The entire and any compensatory process is thereby completely deciphered on a physiologic basis.

The ideas described by us are of particular interest to the physiological analysis of specially psychologic concepts.

For example, the concept of "significance" in learning and in perception of the external world is quite obviously one of the variants of coincidence of the prepared conditioned excitation with return afferentations which are "significant" to this prepared excitation.

All learning takes place with return afferentations necessarily playing a corrective part, and only on this basis is learning possible. Any correction of mistakes is always a result of a failure of the excitations of the acceptor of action to coincide with the return afferentations from an incorrect action. Outside of this mechanism neither *discovery* of a mistake nor its correction is possible. It would be difficult to contest the fact that practically any acquisition of skills (speech, labour, athletic, etc.) proceeds in the sequence shown in the diagram of continuous compensatory adaptation (Fig. 6). All forms of *searching* for objects are based on the peculiarities of the apparatus of the acceptor of action. It would be impossible to "find" an object if the latter did not coincide by all its afferent qualities with the qualities of excitations of the prepared acceptor of action.

It is also interesting to note that even though well-established and automated conditioned reflex acts are performed with the participation of all the aforesaid components of return afferentations they often do not reach the consciousness and develop "unconsciously". Suffice it, however, for the return afferentation not to coincide with the prepared excitations of the acceptor of action as the entire process immediately becomes conscious.

On the same basis any automated action which encounters an impediment during its performance immediately

becomes the object of all-round *conscious* treatment with the result that a way out of the situation is found.

We are reporting our ideas about the supplementary afferent apparatus of the conditioned reflex in their present complete form to the Conference on Psychology for the first time. It is therefore, of course, difficult even to foresee what extensive application they will find in the physiologic analysis of special psychological problems.

The available material warrants the hope that the contact between physiologists and psychologists will be even more complete and successful than ever before.

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THE PHYSIOLOGY OF THE CONDITIONED REFLEX

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Thanks to the basic investigations of Sechenov (1886), Pflüger (1853), Sherrington (1906), Pavlov (1897), Magnus (1924), and others, the modern reflex theory regards the inborn reflex not as a homogeneous and stereotyped form of activity of the nervous system, as was previously assumed, but as a dynamic, changeable and mobile form. It is well known at present that even the simplest inborn reflexes in the most primitive animals may vary greatly in intensity, duration and nature, depending on the condition of the reflex apparatus and of its separate links, on the kind and strength of the stimulus and the duration of its action, and on a number of other internal and external factors. As these reflexes become more and more complex in the course of evolution, so also do their dynamics and lability steadily increase. It is not difficult to understand the biological significance of this lability of the inborn reflexes and of its evolution. Indeed, the central nervous system, being a peculiar "physiological skeleton" of all the functions of the organism, plays the role of the chief agent and regulator of its adaptive activity by means of the reflexes, including those that are inborn. Hence it is clear that the variability of the reflexes raises their adaptive potential, and that the variability itself by its very essence has an adaptive character.

But if the phenomenon of lability is a characteristic and biologically important feature of inborn reflexes the role of which consists mainly in integrating the internal life of the organism with its relatively stable internal factors, what then are the level and significance of the lability of conditioned reflexes which are the chief regulators of the "external life" of the organism, which ensure its finest and most perfect adaptation to the external environment

with its continually changing factors, and which constitute the essence of individual adaptation?

Pavlov regarded the conditioned reflex as the central physiological phenomenon in the activity of the cerebral hemispheres. According to Pavlov, a high degree of lability, its temporary and dynamic nature and dependence on specific conditions are the chief and most characteristic properties of the conditioned reflex. Pavlov (1949) wrote: "It is lability that characterises the nervous phenomena under investigation: every moment and under every condition they take on a new trend" (p. 144). It is obvious that lability, like all the other basic characteristics, is not uniformly manifested in the conditioned reflex. Although the conditioned reflex, which is the basis of individual adaptation, "exists throughout the entire animal kingdom", as stated by Pavlov, this reflex did not remain unchanged. In the process of evolution it rapidly developed, as a result of which there appeared a great variety of conditioned reflexes, different in their character, type, manifestation, degree of complexity, level of development, degree of lability and other characteristics.

Thus, the lability of unconditioned and particularly of conditioned reflexes is marked by the diversity of their forms of manifestation and of the factors by which they are determined. A particularly important type of lability of reflexes is that which is determined by a preliminary change in the condition of the central system of these reflexes resulting from special afferent nerve impulses, which are caused by initial bodily position or by some other stimuli, i.e., by essentially reflex pathways.

This type of lability of reflexes was first revealed approximately one hundred years ago by Sechenov in the reflex activity of the spinal cord; it was subsequently investigated by Sanders-Enz (1867), Goltz (1869), Sherrington (1900), and especially by Magnus on vertebrates, and by Uexküll (1909) and Jordan (1915) on invertebrates. For greater clarity, I shall refer to the first and highly illustrative experiments of Sechenov on spinal frogs. These experiments demonstrated that the initial position of the limbs often predetermines the character of the reflex to be expected from the stimulation of a certain receptive field. For example, if the hind limb which is to be subjected to stimulation is initially flexed, the stimulation of the digits

evokes its extension. On the other hand, if it is initially extended, the same stimulation of the same receptive field calls forth the opposite reflex and the limb is flexed. The analysis of this phenomenon led Sechenov to the conclusion that the initial position of the limb exerts an influence on the functional condition of the spinal reflex apparatus through the corresponding proprioceptive and exteroceptive afferent systems. That is to say, depending on the position of the limb, different intracentral relationships are created between the components of this apparatus, thereby determining the character of the future reflex reaction.

Similar results were obtained by all the other abovementioned investigators. They based their interpretations of this phenomenon mainly on the same point of view as did Sechenov. Magnus, who thoroughly investigated this type of lability of spinal reflexes in dogs and as thoroughly analysed it experimentally, designated it as "switching" (schaltung). It is under this name that this phenomenon has entered modern neurophysiology.

Not long ago Ward (1950), in a series of experiments on cats and monkeys as well as in the course of observations on patients during brain operations, established a new variant of switching. He found that electric stimulation of a certain point in the motor zone of the cerebral cortex, corresponding to a definite limb, evokes one or another type of movement in that limb, depending on its initial position. Moreover, in a series of experiments on animals, Ward demonstrated that this phenomenon disappears after the deafferentation of the limb. Thus he established that in this case, just as in the above-described variant of switching, the lability of the motor reaction is determined by the influence of the flow of nerve impulses which originate in the receptors of the limb and reflect its initial position.

In conditioned reflex activity this type of lability was not subjected to special study for a long time, although individual investigators occasionally made certain observations which suggested its existence. But even aside from these occasional and sporadic observations, there were sufficient theoretical grounds for such an assumption. We have in mind the important proposition of evolutionary physiology that the laws governing the activity of the various organs of the central nervous system, no matter

how specific they are, have common biological roots and many common traits, and that in the activity of these organs, along with particular and specific features, there is a common element which develops according to "a single plan", although at different levels, or, figuratively speaking, along different turns of an ascending spiral. If the phenomenon of switching as a particular form of lability of reflexes was demonstrated in the activity of the primitive central organs, there was reason to believe that this phenomenon, while exhibiting some specific features, was also inherent in the higher central organs the reflex activity of which, as stated above, is characterised by marked lability.

During the past twenty years our laboratory (Asratyan, 1938, 1941, 1954, 1957) has been engaged in special and systematic experimental investigations of the phenomenon of switching in conditioned reflex activity, as a specific form of its lability. Almost simultaneously a number of other scientists, Konorsky and Miller (1936), Laptev (1938) and others, started investigations in the same direction. At present this subject is already attracting the attention of numerous scientists who are engaged in the study of the physiology of higher nervous activity.

I shall turn now to a concise statement of the basic concrete data obtained by us and our collaborators, as well as of our theoretical propositions based on these data.

Drawing an analogy with switching in unconditioned reflex activity, we set ourselves the task of demonstrating experimentally the possibility of elaborating two different conditioned reflex responses to the same stimulus, which could thus evoke one or another conditioned reflex depending on the initial state of the reflex apparatus. The problem, therefore, consisted in simultaneously giving two different signal meanings to a single conditioned stimulus.*

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* The material contained in the rest of this book will be more clearly understood if the reader will keep in mind the fact that the author discusses three types of conditioned reflex experiments:

1. Switching (*pereklyucheniye* in Russian), sometimes redundantly translated as "trans-switching". In these experiments the same neutral stimulus (CS) is reinforced with a different unconditioned stimulus (US) in different situations, e.g., with food in one chamber and with electric shock in another chamber; or different US are used as reinforcement at different times of day or by different experimenters. The same

It should be pointed out that, in the course of studying the so-called heterogeneous conditioned reflexes. Pavlov's laboratories long ago obtained a number of data which show that the usual signal meaning of a conditioned stimulus can be changed quickly and temporarily to another meaning. If, for example, in experiments with heterogeneous conditioned reflexes some stimuli are alimentary signals while others are electric defence signals, it is possible by means of preliminary intensification of the excitability of the food centre (for example, by starving the experimental animal) to make the electric defence conditioned stimuli evoke an alimentary reaction. An opposite effect can be obtained by first decreasing the alimentary excitability or by intensifying the excitability of the defence centre. A temporary change of the signal meanings of the conditioned stimuli can also be effected in another way. If soon after the feeding of the animal, i.e., when its food centre is still in a state of excitation, we apply an electric defence conditioned stimulus, this evokes an alimentary conditioned reflex, and not one of electric defence. Similarly, an alimentary conditioned stimulus which follows residual excitation of the defence centre evokes an electric defence

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neutral stimulus thus acquires the property of provoking a different conditioned reflex (CR) under different circumstances.

2. Dual or binary conditioned reflexes (*dvoiniye* or *binarniye* in Russian). A dual CR is developed by reinforcing the same CS *simultaneously with two different US* (e.g., food and electric shock to a paw), so that the animal eventually gives a dual response to the same CS (e.g., simultaneously lifting the paw and salivating).

3. Bidirectional conditioned connection (*dvustoronnaya uslovnaya svyaz* in Russian). The author states that when a conditioned reflex is being developed, two connections really take place:

a) a direct CR where the CS evokes the CR;

b) a reverse CR where the application of the US alone provokes a response corresponding to the CS, e.g., when a mild electric shock to the paw (CS) is reinforced with food (US), eventually application of electric shock will induce conditioned salivation (a direct CR). When food is presented (US) to the animal it will provoke a lifting of the paw, i.e., a conditioned motor defence reflex (a reverse CR).

The Russian phrase *dvustoronnaya uslovnaya svyaz* literally means a bilateral conditioned connection. The word "bilateral" has a specific anatomic connotation, implying responses by two symmetric organs or extremities. This anatomic connotation, however, is not involved in these experiments and is therefore confusing. For this reason we have used the word "bidirectional".—S.A.C.

conditioned reflex (according to the data of Konradi, 1932, and Konorsky and Miller).

This type of rapid and transitory modification of the signal meaning of a stimulus is somewhat similar as to physiological mechanism to the phenomenon which manifested itself especially strongly in the well-known experiments of M. N. Yerofeeva (1912), and which vividly demonstrated the significance of the relative excitability of various unconditioned reflex centres in determining the character of conditioned reflex activity. In all these cases, the laws governing the inborn forms of activity of the central nervous system, result in switching nerve impulses from some pathways to others, thus causing one reflex or another. It is precisely this phenomenon which Pavlov (1949) had in mind when he spoke of the "switching of the nervous current", and when he stated that "on reaching the higher part of the nervous system the stimulus is transmitted now in one direction and now in another, depending on the given conditions" (p. 207).

In all these experiments the modification of the signal meaning of the conditioned stimulus was not specially elaborated, but occurred because of an accidental predominance of the excitability of one unconditioned reflex centre over another, i.e., it was the result of the laws governing inborn nervous activity. The mechanism of these phenomena has much in common with the mechanism of the phenomena of reversal, dominant, etc., which were demonstrated by some investigators during direct or reflex stimulations of the cortex under acute experimental conditions. We have in mind, for example, the experiments of Graham Brown and Sherrington (1912) in which it was established that if, after stimulation of the cortical point which leads to the flexion of one of the limbs we stimulate the cortical point usually causing its extension, we will then obtain flexion of the limb in this case, also, instead of extension. Experiments of a similar sort by Ukhtomsky (1927) demonstrated that if, for example, after a reflex excitation of the swallowing centre we stimulate the cortical point of an extremity, this will not result in a movement of that extremity, but in a swallowing movement.

In our laboratory we tried to solve a somewhat different problem: to carry out a special elaboration of two stable

conditioned reflexes to the same stimulus, i.e., establishing two different and constant signal meanings for the same stimulus. Such a switching would not be subject to the laws of the inborn forms of nervous activity, but to those of the acquired forms of this activity.

Our experimental procedure was essentially as follows. In its initial stage our collaborator F. M. Sheetov (1937) performed the following experiments on dogs: in the morning, by pairing metronome tones of 120 beats per min with food, he converted those tones into a positive alimentary conditioned stimulus; he differentiated from them metronome tones of 60 beats per min by not reinforcing with food, i.e., he converted the latter into a negative conditioned stimulus. After these reflexes had been stabilised another investigator, V. V. Yakovleva, conducted different experiments in the same chamber on the same dogs and on the same day, but some hours later. She systematically paired the metronome tones of 120 beats per min with stimulating the dog's paw by electric current. Several days later the dogs developed an *electric defence* reflex to this stimulus during experiments conducted in the afternoons, while in the mornings the metronome tones of 120 beats per min acted as a positive *alimentary* conditioned stimulus.

The following observation is quite interesting. After the electric defence reflex to 120 beats per min had been formed and reinforced in afternoon experiments, the differentiation to 60 beats per min of the metronome was immediately evident during the very first application. Subsequently a number of other stimuli were turned into alimentary conditioned stimuli by the first experimenter in morning experiments and into electric defence conditioned stimuli by the second experimenter during afternoon experiments.

These experiments thus made it possible to give the same stimulus two different positive signal meanings so that it evoked a conditioned reflex of one kind or another, depending on the circumstances.

Special experiments demonstrated that the investigators themselves were the agents of switching the conditioned reflexes in the above-described cases. When the experiments were conducted by Sheetov the stimuli had an alimentary signal meaning, irrespective of the time of day and the

sequence of the experiments, while the same stimuli in the experiments conducted by Yakovleva had an electric defence signal meaning. Moreover, when during control experiments the devices used for alimentary conditioned reflexes or electric defence conditioned reflexes were attached to various parts of the animal's body, the results of the experiments were not noticeably affected. When, however, both Sheetov and Yakovleva were present at the experiments, the result was considerable confusion in conditioned reflex activity, i.e., the dogs reacted to the stimuli sometimes as to a food signal, sometimes as to an electric defence signal, and sometimes their reactions were mixed.

We established through other experiments that numerous other factors might be the switching agents of conditioned reflexes, such as changing the chamber, alterations in the equipment of the chamber, changes in the time or sequence of the experiments, etc. For instance, if both experiments on the same dog are conducted by the same investigator in the same chamber but at different times of day and in a definite, unvarying sequence, it is possible to turn the same stimulus into an alimentary conditioned signal in one series of experiments and into an electric defence conditioned signal in another series of experiments. The results will be similar if the same investigator conducts each of the experiments in a separate chamber; in that case the time of day and sequence of experiments is of no essential importance. These and other factors can each become separate switching agents, but their combination facilitates this complicated transformation in the activity of the cerebral hemispheres and can prevent possible disturbances.

It has been demonstrated in our laboratory that animals can solve even more complicated problems connected with the switching of different conditioned reflexes. M. I. Struchkov (1956) formed two different conditioned reflexes in dogs in the same chamber, i.e., an alimentary conditioned reflex to the sound of a buzzer and an electric defence reflex to a tactile skin stimulus. After these conditioned reflexes had become well stabilised, Struchkov began parallel experiments on the same dogs in different chambers, this time pairing the tactile skin stimulus with food and the buzzer with electric stimulation of the paw. The experi-

ments conducted in the second chamber had considerable influence on the conditioned reflex activity of the dogs when they were placed in the first chamber. The important point, however, is that the dogs finally solved the difficult and complicated problem in a rather clear-cut and precise way, after overcoming the resultant neurotic state, and after passing through the phase of double conditioned reflex action to each of the stimuli and the phase of gradual increase of adequate reaction and decrease of inadequate reaction to each stimulus in a given chamber (Fig. 1).

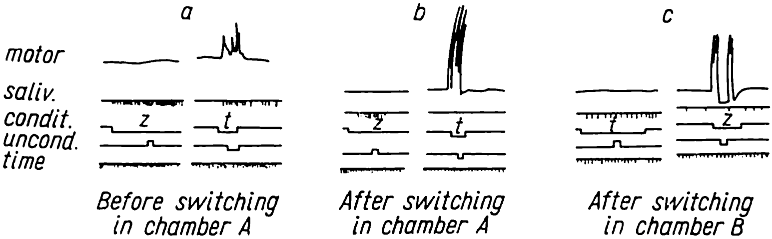


Fig. 1. Kymogram of conditioned reflexes in a dog (a) before the elaboration of a switch in chamber A: a conditioned salivary alimentary reflex (in drops) to the sound of a buzzer (z) and a double conditioned reflex (electric defence and alimentary) to a tactile stimulus (t); (b) after the elaboration of a switch in the same chamber: a conditioned salivary alimentary reflex to the sound of a buzzer (z) and a conditioned electric defence motor reflex to a tactile stimulus (t); (c) after the elaboration of a switch in chamber B: a conditioned salivary alimentary reflex to a tactile stimulus (t) and a conditioned electric defence motor reflex to the sound of a buzzer (z)

In a special series of experiments we also demonstrated that it is possible to form a positive and a negative conditioned reflex of the same kind to a single stimulus, i.e., that it is possible to switch conditioned reflexes from one functional sign to the opposite sign within the limits of a single type of activity of the organism, giving the same stimulus the ability either to activate or to inhibit a specific function (unpublished experiments by F. M. Sheetov and V. A. Zamyatina). The very same investigator conducted two experiments on dogs in the same chamber: one in the morning and one in the afternoon. In both experiments only alimentary conditioned reflexes were formed and only

to the same stimuli. The only difference between the two experiments was that in the morning experiment all conditioned stimuli, without exception, were reinforced by food, whereas in the afternoon experiment one of the stimuli was not reinforced by food. That particular stimulus acquired, as a result of the experiments, a double signal meaning: in the morning experiments, like all the other stimuli, it acted as a positive alimentary conditioned stimulus, while in the afternoon experiments, unlike the other stimuli, it acted as a negative conditioned stimulus, causing no reflex.

We subsequently demonstrated that animals can also solve more complicated problems of switching conditioned reflexes of one kind but of opposite functional signs. In the morning experiments Sheetov (1939) paired a loud tone with food, while a soft tone was not paired with food; he reversed the procedure in the afternoon experiments conducted in the same chamber and on the same dogs, pairing the soft tone with food while the loud tone was not paired with food. The aim was to give each of these two similar stimuli opposite signal meanings within the limits of one kind of conditioned reflex activity. The problem proved to be rather difficult and in these experiments it was not solved by all the dogs. Some of the dogs solved it, though not in a very well-defined manner. In the morning experiments the loud tone evoked the positive conditioned reflex and the soft tone either did not produce it at all or evoked it in a weak form. Conversely, in the afternoon experiments the soft tone evoked the positive alimentary conditioned reflex, while the loud tone produced it in a weak form.

The experiments of my colleague Y. M. Pressman (1941) (somewhat similar to those of Y. Konorsky and S. Miller) show that it is also possible to switch conditioned reflex activity, i.e., to change the signal meaning of the stimulus within the limits of one kind and one sign of conditioned reflexes. Pressman attached electrodes and a movement recording device to the right hind paw of a dog and by pairing various neutral stimuli with electric stimulation of that paw, produced corresponding motor electric defence conditioned reflexes. When the conditioned reflexes in the right paw were established, Pressman conducted another experiment: he attached the same electrodes and recording

device, not to the right paw but to the left, which had never before been stimulated with electric current and in which no conditioned reflex had been developed. The very first time the conditioned signal was applied, the dog raised its left hind paw, i.e., the paw to which the electrodes and the recording equipment had been attached for the first time (Fig. 2). Obviously in this case, as in similar experiments by Konorsky, the switching of the conditioned reflexes from one paw to the other was caused by the act of attaching the recording devices and the electrodes to the paws. When in another experiment the electrodes and the devices were attached to both hind paws, the dogs became confused. The first time the conditioned stimulus was applied, the dog lifted and put down first one hind paw and then the other in turn. But after the very first electric stimulation of one of the paws, all subsequent reactions took place in that paw only.

Thus in the first series of Pressman's experiments the switching of the conditioned reflex activity was due to the act of attaching the electrodes and the recording device to the dog's paws, whereas in the second series of experiments this role was played by the first stimulation of the paw by electric current.

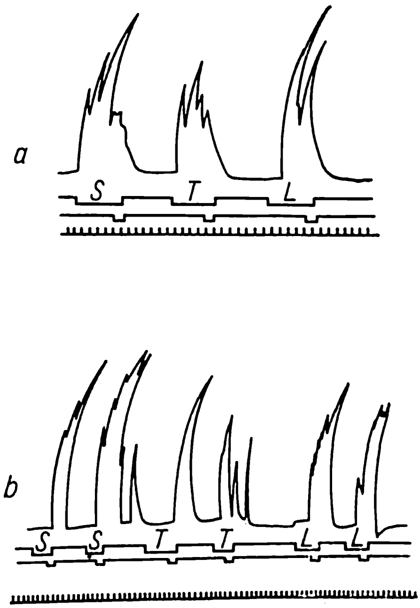


Fig. 2. Kymogram of electric defence conditioned reflexes to the sound of a buzzer (S), to a tactile stimulus (T), and to light (L) in dog "Jan". (A) in the right hind paw to which the electrodes and the recording device were previously attached and in which reflexes have been elaborated; (b) in the left hind paw to which the electrodes and the recording device were attached for the first time. From top to bottom: reflexes; lines of the conditioned stimulations; lines of the unconditioned stimulations; time in sec

Until recently we and our co-workers and other scientists were investigating the kinds of elaborated switching in conditioned reflex activity in which, depending on conditions, the stimulus either signalled different activities, i.e., activated different functions of the organism, or gave two opposite signals in the same activity, i.e., activated one specific function. But the following question still remained unsolved: is it possible to elaborate a kind of conditioned reflex switching in which a single conditioned stimulus would call forth two conditioned reflexes of the same type (for example, two alimentary reflexes), and of the same functional sign (for example, positive), but of different magnitude and different latency, depending on specific conditions? In other words, is it possible within the limits of a signal meaning of one kind and of one sign to give to a single conditioned stimulus different properties, specifically, the ability to evoke either a weak or a strong positive conditioned reflex with a short or a long latency?

In this connection should be recalled the early observations of Pavlov's collaborators, and especially data yielded by the later researches of Kleshchov (1936), Nikitin (1933) and others, according to which the intensity of a conditioned reflex may be determined not only by the intensity of the conditioned stimulus, but also by that of the unconditioned reflex on the basis of which it was elaborated. Specifically, the above-mentioned investigators established that by means of a substantial increase or decrease in the intensity of the unconditioned reinforcement and consequently in that of the unconditioned reflex, it is possible to obtain a considerable corresponding increase or decrease in the intensity of the conditioned reflex which was elaborated on the basis of this unconditioned reflex to the same stimulus without changing the intensity of this stimulus. Further, the results of numerous investigations carried out in Pavlov's laboratories showed that by varying the delay of the reinforcement of the conditioned reflex to a certain stimulus it is possible to obtain a corresponding change in the latent period of this conditioned reflex, for example, to convert it from a short latency to a long latency reflex, and vice versa.

It is easy to see that these two kinds of experiments were aimed at the solution of problems which are quite different from those mentioned earlier. In both cases, i.e.,

in the experiments where the intensity of the conditioned reflex is modified by a corresponding change in the magnitude of the reinforcing unconditioned reflex, as well as in the experiments where the latent period of the conditioned reflex is modified by a corresponding change in the time of delay of the reinforcing unconditioned reflex, the conditioned stimulus at a given time has the ability to evoke only one of two possible conditioned reflexes: either strong or weak, with either a short latency or a long latency.

On the basis of these as well as other observations we could, of course, easily yield to making various conjectures and theories concerning the possibility of solving the above problems by higher animals, i.e., of elaborating those characteristics of the conditioned stimulus whereby, in accordance with these or other conditions, it could at a given moment evoke either a strong or a weak conditioned reflex, with either a short or a long latency. But no matter how justified and probable such conjectures may seem, they cannot replace precise laboratory experimentation in the solution of complex scientific problems, especially of such intricate problems of higher nervous activity as the possibility of giving to a single conditioned stimulus simultaneously two different signal meanings within the limits of one type of reflex and one functional sign. That is why we considered it necessary to concern ourselves with the direct experimental investigation of these still unsolved questions regarding the problem of elaborated switching in conditioned reflex activity. With this aim, appropriate experiments were carried out in our laboratory by two young Chinese physiologists, Zhu Zi-Jiao and Yan Wei-Jin.

The experiments of Yan Wei-Jin (1957) were as follows. In one chamber (I) she elaborated in dogs alimentary conditioned reflexes to acoustic, visual and tactile stimuli, reinforcing each of these stimuli with 20 g of powdered dried meat and bread. When the conditioned reflexes to all the stimuli reached adequate strength and stability in this chamber, the experimenter started new experiments in another chamber (II), the same stimuli this time being reinforced with 60 g of the same food. Finally, the experiments were performed in each chamber in turn, one day in the first chamber and one day in the second, the stimuli being reinforced with portions of 20 g and 60 g of food

respectively. In order to ensure an approximately equal alimentary excitability, the experiments were carried out at the same hour in both chambers. In order to avoid the formation of a stereotype, the sequence of the stimuli and the intervals between their application were continually varied in both experiments. The conditioned stimuli were delayed for 15 sec in both cases.

Disregarding the variations observed in the results of the experiments which were determined by individual peculiarities of the experimental animals, as well as many interesting details which characterised the dynamics of the development of these phenomena, we shall dwell here only on the essentials common to all the experimental animals. The alimentary conditioned reflexes to all stimuli underwent a number of phasic changes in both chambers and finally reached a relatively stable strength which was, however, different for each chamber: in chamber II it was almost one and a half to two times as great as in chamber I; in chamber II the latent period of the conditioned reflex was shorter, while the intensity of the conditioned salivation was greater than in chamber I. The above can be illustrated by data which were recorded during the final stages of experiments carried out on two dogs in both chambers. In the dog Likhe in chamber I the visual signal for a period of 15 sec evoked a conditioned reflex equal in strength to 29 divisions of the scale, whereas in chamber II this conditioned reflex equalled 56.2 divisions. The action of a tone produced 25.5 divisions in chamber I and 63 in chamber II. In the dog Solovei the corresponding figures were: for the visual signal, 59 and 80 divisions; for the tactile stimulus, 56 and 81.2 divisions; and for the tone, 44 and 76 divisions (Fig. 3).

The experiments performed by Zhu Zi-Jiao (1957) on dogs were of a different kind. First, alimentary conditioned reflexes to auditory, visual and tactile stimuli were elaborated in one chamber by means of reinforcement of each of these stimuli with 60 g of powdered dried meat and bread. In order to demonstrate conditioned reflexes, the unconditioned stimuli alone were applied for 15 sec, after which the food was presented. When the conditioned reflexes reached adequate strength and stability in this chamber, the experimenter started new experiments in the second chamber; the difference between the experiments

carried out in the first chamber and those in the second was that in the second chamber portions of food of the same amount and kind were presented to the animals not 15 sec after the conditioned stimuli began to act, but after a delay of one or two minutes. From that time on the experiments were performed alternately in each chamber, the same stimuli being reinforced with the same amount of food, presented after a delay of 15 sec in the first

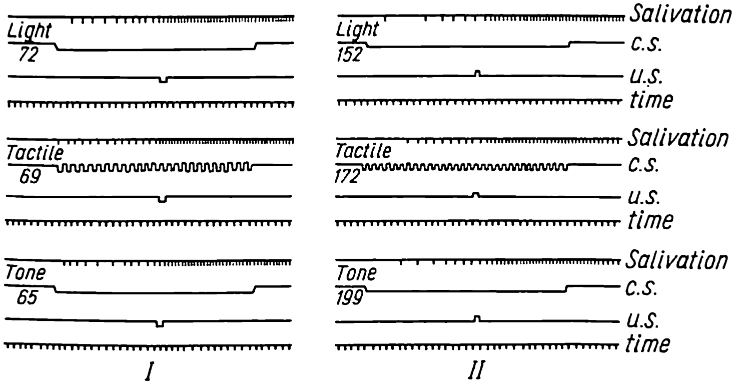


Fig. 3. Kymogram of salivary alimentary conditioned reflexes to light, to a tactile stimulus and to a tone elaborated in the chambers by means of reinforcement with large portions (I) and small portions (II) of food. From top to bottom: salivary reflex in drops; c.s.—conditioned stimulus; u.s.—unconditioned stimulus; time in sec

chamber and after a delay of one to two minutes in the second chamber. The experiments took place at the same hour but, as in the previous experiments, the sequence of the stimuli and the intervals between them were constantly varied.

These experiments revealed certain individual peculiarities among the animals, but here we shall dwell neither on these peculiarities nor on the data which characterise the development of different phases in the solution of this problem. The most important result of the experiments is the following observation which was common to all the experimental animals: whereas in the first chamber all the conditioned stimuli evoked in the animals reflexes with a short latent period, in the second chamber they produced reflexes with much longer latent periods. The short latency

conditioned reflexes were considerably weaker than those with long latency. For example, in comparable experiments of this stage the latent period of a conditioned reflex elaborated in the dog Dadutz to a tactile stimulation of the skin was 7 sec in the first chamber and 25 sec in the second chamber; the latent period of a conditioned reflex to the visual stimulus was 4 sec and 34 sec respectively, and to a tone 4 sec and 8 sec. In the dog Tarzan the corresponding latent periods of the conditioned reflexes were: to a tone 3 sec and 26 sec; to a tactile stimulation of the skin, 2 sec and 16 sec; to the visual stimulus, 2 sec and 32 sec. The diagram (Fig. 4) shows the dynamics of the elaboration of this variant of switching conditioned reflexes, or, to be more precise, the dynamics of modifications in the durations of the latent period of salivary conditioned reflexes as well as in their magnitude at the three basic stages.

It should be observed that the elaboration of variously delayed and variously reinforced alimentary conditioned reflexes to the same stimuli also proved possible when experimentation was conducted on the same animals in the same chamber and at the same time of day, but by different experimenters and on different days.

Of considerable interest are the following data obtained on dogs by Yan Wei-Jin and Zhu Zi-Jiao after the successful elaboration of differently delayed and differently reinforced conditioned alimentary reflexes. If at this stage of experimentation a conditioned reflex of a given delay (for example, a short latency reflex), or of a given amount of reinforcement (for example, the small reinforcement) has been elaborated to the new stimulus in one chamber, then the very first application of this stimulus in the other chamber produces a conditioned reflex with the delay characteristic of the second chamber (a long latency reflex), or of the corresponding amount of reinforcement (large reinforcement). In this case also the *tonic* conditioned reflex background (represented by the particular conditioning chamber—*Ed.*) determines the character of the *phasic* conditioned reflex (i.e., the conditioned reflex obtained in response to a specific conditioned stimulus—*Ed.*). Furthermore, if in one chamber we completely extinguish the conditioned reflex to a certain stimulus, the conditioned reflex to the same stimulus in the other chamber also becomes markedly inhibited. Obviously, under our experi-

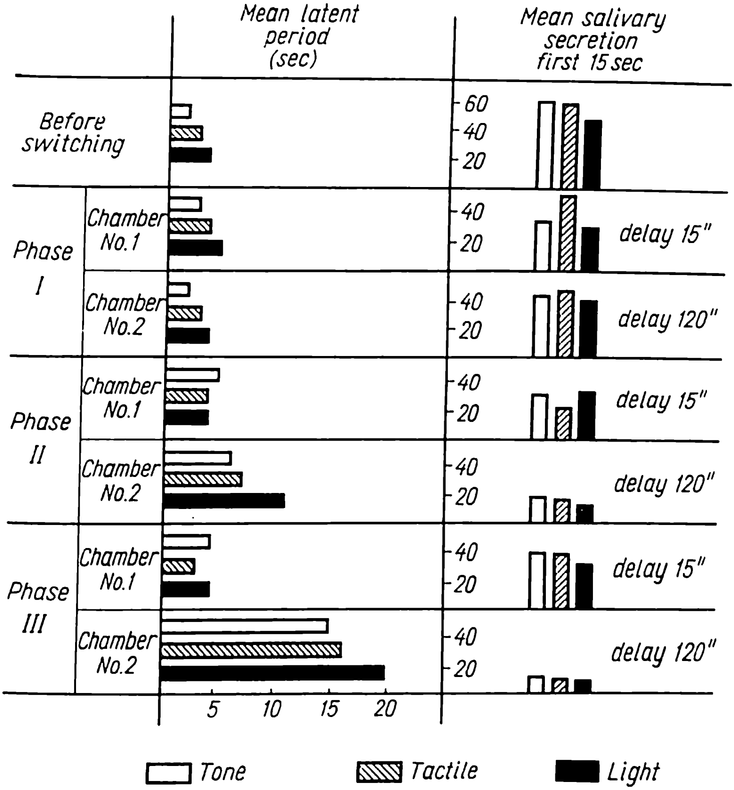


Fig. 4. Diagram showing changes in the average duration (in sec) of the latent periods (horizontal bars) and intensity (vertical bars) of salivary conditioned reflexes to a tone, a tactile stimulus and light in the course of elaborating a switch to the respective durations of the latent periods

mental conditions both of the differently *reinforced* conditioned alimentary reflexes to the same stimulus, as well as both of the differently *delayed* conditioned reflexes to the same stimulus, are effected by the same nervous structures.

Thus, these experiments show that it is possible to elaborate in dogs the switching both of differently reinforced and of differently delayed positive alimentary conditioned reflexes to the same stimulus. It should be pointed out that the achievement of this result proved to be quite difficult for the experimental dogs. Some of them went

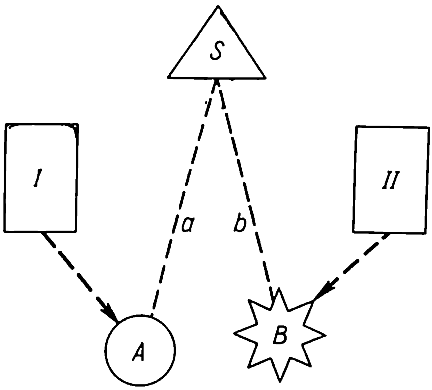
into a state of neurosis even during elaboration of the switching, while others did so after its termination; this led sometimes to the disruption of the level of switching already attained, sometimes to the breakdown of the entire conditioned reflex activity, and even to changes in the external behaviour of the dogs. Only a recess in the experimental work, and in some cases the administration of moderate doses of bromide preparations, made it possible to overcome these difficulties and to normalise the disturbed higher nervous activity in the experimental animals.

What, then, is the physiological mechanism of the above-described phenomena, and what are our theoretical concepts in regard to switching in conditioned-reflex activity?

We believe that the constant factors of the environment or of the experimental conditions which we designate as "switching agents" (different chambers, experimenters, hour of experimentation, sequence of the experiments, etc.) and which in the final analysis determine the signal meanings of ordinary conditioned stimuli of short duration, are in effect conditioned stimuli in themselves. *But these stimuli, just like the conditioned reflexes which they evoke, are of a specific type* and differ from ordinary conditioned stimuli and reflexes. The constantly acting factors of the environment or of the experimental conditions, which are at first neutral, gradually become *constantly acting conditioned stimuli* which can evoke *conditioned reflexes of a tonic type,* and create a definite functional background or readiness for phasic activity. These tonic conditioned reflexes can specifically adjust the phasic conditioned reflex pathways and mechanisms and thereby predetermine the type and functional sign or character of the phasic conditioned reflexes which emerge against this background, as well as the direction of the phasic conditioned reflex activity in general.

With regard to the elaborated switching of heterogeneous conditioned reflexes, for example, the above statements can be graphically illustrated by a diagram (Fig. 5) which shows the various cortical points of the stimuli and the connections between them. A conditioned stimulus (with cortical points S) in one of the chambers (I) is linked by a phasic conditioned connection (a) with an unconditioned

Fig. 5. Diagram showing the switching of heterogeneous conditioned reflexes



alimentary reflex (with cortical point λ and evokes an alimentary conditioned reflex along the chains S ⟶ a ⟶ A. The same stimulus in the other chamber (II) is also linked by a phasic conditioned connection (b) with an electric defence unconditioned connection (B) and evokes a corresponding conditioned reflex along the chain S⟶b⟶B. The specific manifestation of one or the other of the heterogeneous signal meanings peculiar to this conditioned stimulus, is determined by the fact that corresponding tonic conditioned reflexes to the switching agents have simultaneously been elaborated, i.e., an alimentary reflex to chamber I and an electric defence reflex to chamber II. On the diagram the tonic conditioned reflexes are designated by arrows: I⟶A and II⟶B. This does not mean that the tonic conditioned-reflex modification of the functional state which takes place in each chamber is in one case confined only to the cortical point of the alimentary unconditioned reflex, and in the other case to that of the electric defence reflex. There are definite reasons to assume that this conditioned-reflex modification is accompanied by a change in the functional state of the corresponding *phasic* conditioned connections and even of the cortical points of the conditioned stimuli.

It is probable that the changes in the functional state of these two structures are of a secondary nature and that they are determined by tonic conditioned reflex changes in the cortical points of the corresponding unconditioned reflexes, just as it takes place (according to the latest neurophysiological data) in the nervous structures of simple reflex arcs during the appearance in them of so-called local excitation and during the decrement of the latter by diffusion in all directions, including the antidromal. In this case the connection of the switching agents with the cor-

responding cortical points of the unconditioned reflexes can be designated, as in Fig. 5, by chains I—A—a—S and II—B—b—S. It is possible, however, that each of the switching agents is connected directly with each of these chief cortical links of the phasic conditioned reflexes, and can consequently modify their functional state directly, but simultaneously and in the same direction as the changes in the functional state of the cortical point of the unconditioned reflex. In this case, the schematic presentation of these interrelations has to be complicated, and the diagram must be changed by at least adding two arrows pointing from each switching agent to the corresponding phasic conditioned connections (I⟶a and II⟶b) and to the cortical point of the conditioned stimulus which is common to the phasic conditioned reflexes of both types (I—S and II—S).

We now have new data which may be regarded as direct experimental corroboration of our hypothesis to the effect that the phenomenon of switching represents a tonic conditioned reflex. Our co-worker G. T. Sakhiulina (1955) investigated the phenomenon of switching in conditioned reflex activity in dogs by means of the usual methods of conditioned reflexes combined with electroencephalography. In experiments performed in the morning an auditory stimulus was paired with the electric stimulation of the dog's left hind leg, while in the afternoon experiments the same auditory stimulus was paired with the electric stimulation of the right hind leg. The experiments established the possibility of elaborating a switch in the dog's conditioned reflex activity (i.e., in the morning the auditory stimulus caused the dog to lift its left hind leg and in the afternoon its right hind leg). At the stage of distinct switching in the conditioned reflexes a new and interesting phenomenon in the EEG of the dogs was observed: as soon as the preparation of the animal for the experiment was begun (i.e., when it was brought to the chamber and placed on the stand, when the necessary instruments were attached to different parts of its body, etc.), there appeared a focus of heightened electric activity in the anterior parietal area of the cortex in the cerebral hemisphere homolateral to the activated leg. This focus of heightened electric activity persisted throughout the experiment. From the sections of the electroencephalograms of two such

experiments shown in Fig. 6 it can be seen that during the morning experiments this focus emerges in the above-named area of the cortex of the left hemisphere while during the afternoon experiments it appears in that of the right hemisphere. An auditory, i.e., phasic, conditioned stimulus applied against this background, at the time of its action increases the degree of electric activity of other cortical points and simultaneously intensifies even more the electric activity of the particular point. It is noteworthy that topographically this point coincides quite closely with the cortical point which, according to Bremer (1953) and others, integrates the postural reflexes.

Thus, the above experimental data regarding the nature of the electric activity of the cortex clearly show that two types of conditioned reflexes actually develop and appear during elaborated switching in conditioned reflex activity: *tonic conditioned reflexes* determined by the constant

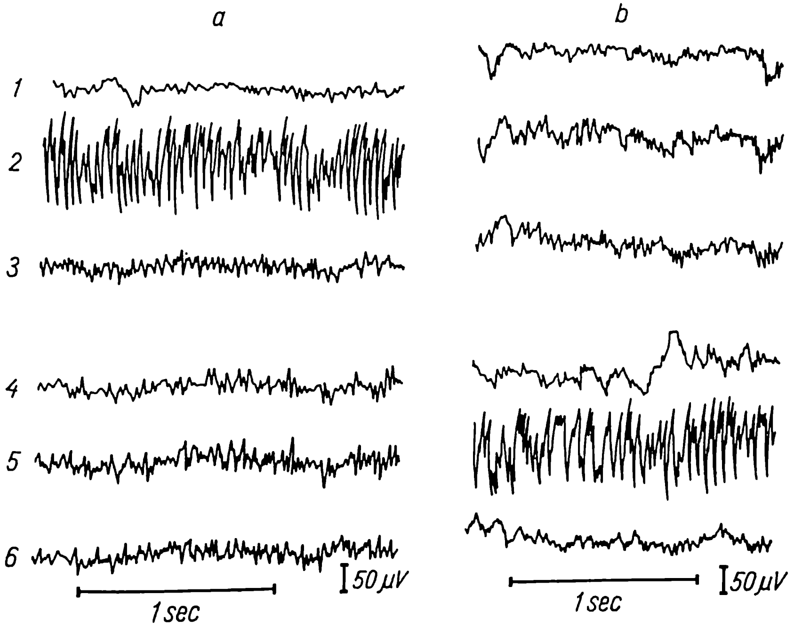


Fig. 6. Electroencephalogram of the dog Tsygan during a switch of electric defence motor conditioned reflexes from one extremity to another. (a) Morning experiment; (b) afternoon experiment. 1,2,3—leads from the left cerebral hemisphere. 4,5,6—leads from the right cerebral hemisphere

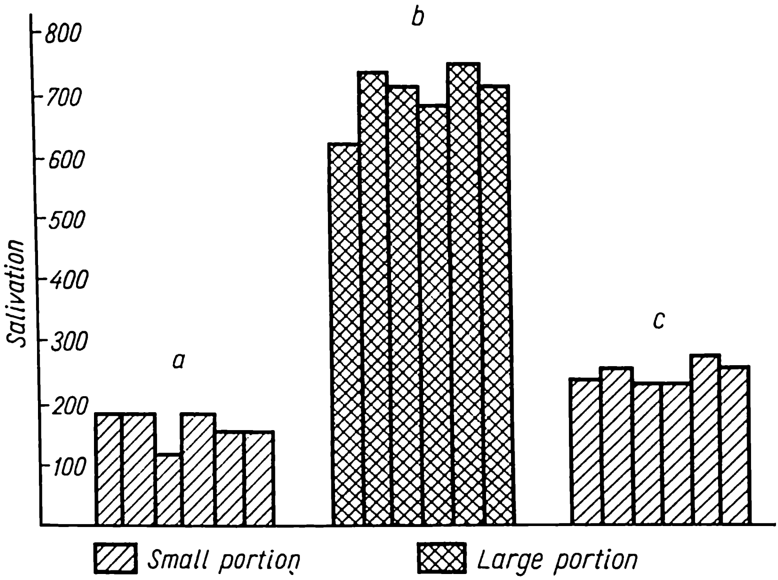


Fig. 7. Diagram showing the magnitude of salivary reflexes in a dog to portions of 10 g of powdered dried meat and bread before (a), and after (c), a series of experiments using 50 g portions (b)

factors of the experimental conditions, and *phasic conditioned reflexes* which emerge against this background and which are evoked by the application of specific short-acting conditioned stimuli.

The following data obtained in our laboratory by Khachaturyan also testify to the formation of tonic conditioned reflexes. We first determined as precisely as possible the salivary reflex produced in the dog by a standard portion of dried bread and meat (10 g) under the conditions of the experimental chamber. All the values obtained in this way were in general almost identical. Then, during a period of more than a week, in the same chamber the dog received considerably larger portions of the same food (50 g or more); this of course evoked a much stronger salivary reflex. After this series of experiments we resumed feeding the dog with the original size portions of dried bread and meat (10 g); this time the salivary reflex proved to be stronger than originally. Figure 7 shows the values of the salivary reflexes observed at the three stages of experimentation described above. It is noteworthy that after several days of feeding the dogs for the second time

with 10 g portions, the salivary reflex gradually diminished and returned to its initial value.

In order, however, to interpret, in the light of the concept of the tonic conditioned reflex, both these data and the previously described new data regarding the elaborated switching of differently reinforced and differently delayed conditioned reflexes, we consider it necessary to say a few words about our theory of the mechanism which determines the increase or decrease in the magnitude of positive conditioned reflexes, as well as the duration of their latent period.

Taking into account some of the latest advances in the general physiology of excitable tissues, and on the basis of these and some of our other data, we propose a theory which is in accord with one of the principal hypotheses of modern neurophysiology, the development of which we owe primarily to British physiologists. We refer to the hypothesis that the intensity of nervous processes is determined mainly by the number of activated units. In complete agreement with this, we believe that the strength of unconditioned and conditioned reflexes in a normal organism is chiefly determined by the number of functioning nervous units, i.e., by the number of nerve cells in the cortical points of the corresponding stimuli which are reflexly activated by these stimuli. All other conditions being equal (level of excitability, duration of the stimulus, etc.), the stronger the unconditioned and neutral stimuli, the greater, within certain limits, will be the number of component elements of the conditioned connections which arise between them in the course of their combined action, i.e., the greater is the potential power of these connections. A change in the magnitude of an elaborated conditioned reflex caused by a protracted change in the magnitude of the unconditioned reinforcement may be regarded largely as an expression of a change in the number of functioning units in the cortical point of the unconditioned reflex, and subsequently in the conditioned connection. This would also seem to explain satisfactorily all other known phenomena relating to changes in the magnitude of conditioned reflexes in response to changes in conditioned and unconditioned stimuli which occur either separately or simultaneously, in either the same or opposite directions.

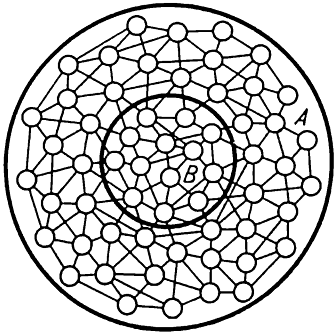
We shall now attempt to apply these concepts to the

interpretation of the above-described data concerning tonic conditioned reflexes elaborated in response to different magnitudes of food portions as well as data concerning switching of differently reinforced and differently delayed conditioned reflexes.

The increase in the magnitude of the salivary reflex to a small portion of food (10 g) after many days of feeding the dog large portions (50 g) of the same food, we interpret as follows. Under practically identical experimental conditions and degree of alimentary excitation of the dogs, the small portion of food excites considerably fewer nerve cells in the cortical point of the unconditioned alimentary reflex (ring B in Fig. 8) than does the large portion of the same food (ring A). Systematic feeding of the dog for many days with a large portion of food under stable experimental conditions produces in the dog a tonic alimentary conditioned reflex of an intensity appropriate to the environmental factors, i.e., a tonic conditioned reflex increase in the excitability of an adequate number of cells (ring A) in the cortical point of the unconditioned alimentary reflex. After a transition from large to small portions of food, this heightened tonic conditioned reflex excitability of an inappropriately large number of cells in the cortical point of the unconditioned reflex, makes the reflex to these small portions more intense than before. Subsequently this increase in intensity of the reflex to small portions of food gradually diminishes and disappears for lack of reinforcement of the tonic conditioned reflex with large portions of food.

We explain the results of our experiments with the elaboration of differently reinforced conditioned reflexes as follows. In the chamber where the dog receives large portions of food the number of nerve cells in the cortical representation of the alimentary unconditioned reflex which are stimulated is greater than in the chamber where the dog receives small portions of the same food (in Fig. 9 they are designated by ring A and its counterpart, ring B). In each chamber, corresponding to the intensity of the alimentary unconditioned reflex, we eventually elaborated two types of conditioned reflexes: *tonic* conditioned reflexes to the switching agent, i.e., to the specific conditions of the chamber itself, and *phasic* conditioned reflexes to the specific, short-acting stimuli (in the figure the tonic

Fig. 8. Diagram showing a tonic conditioned alimentary reflex to experimental environment



connections with chambers I and II are designated by the thick arrows *a* and *b*, while the phasic conditioned connections are designated by vertical broken lines). When, after elaboration and stabilisation of the conditioned reflexes, the experiment is performed in chamber I, the strong tonic conditioned reflex becomes active at once: in the cortical structures of the food centre there appears a stable local excitation comparable in strength to the unconditioned reflex excitation in this centre evoked by the presentation of large portions of food (ring A). Because of this a change takes place at the same time in the functional state of the phasic conditioned connection of corresponding intensity. When, on the other hand, the experiment is performed in chamber II, it is the weaker tonic conditioned reflex which becomes active: in the cortical structures of the food centre there appears a local excitation comparable in strength to the unconditioned reflex excitation in this centre evoked by the small portions of food (ring B). Because of this a change also takes place in the functional state of correspondingly fewer component elements of the phasic conditioned connection. For this reason, the same phasic conditioned stimulus, when acting in chamber I, i.e., against the background of the larger tonic alimen-

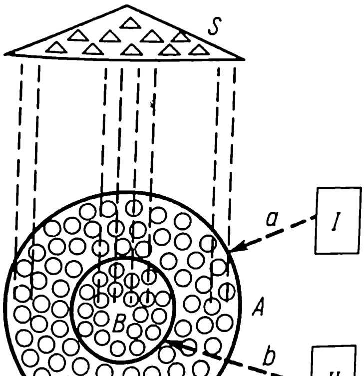


Fig. 9 Diagram representing the switching of differently reinforced homogeneous conditioned reflexes of the same kind

tary conditioned reflex, evokes the larger phasic conditioned reflexes, and when acting in chamber II, i.e., against the background of the smaller tonic alimentary conditioned reflex, produces the smaller phasic reflexes.

It is more difficult to explain the data concerning the switching of differently delayed conditioned reflexes. This is due to the fact that in general it is not easy to imagine clearly, and especially to present graphically, the phase of inhibition of a positive conditioned connection which precedes the phase of its excitation and which is known as delayed inhibition in the same kind of conditioned reflexes or as the "latent period" of moderately delayed conditioned reflexes. Moreover, the question of the localisation of conditioned inhibition in the links of the arc of a conditioned reflex still remains unsolved. On the basis of certain data (which will be dealt with in Chapter 6—Ed.), we believe that conditioned inhibition, including its variations mentioned above, arises in the elements of the conditioned connection itself and not in the cells of the cortical point of the conditioned stimulus, as Pavlov supposed, nor in the cells of the cortical point of the unconditioned stimulus, as some of Pavlov's pupils believe.

If this is the situation as regards the more elementary phenomena, is it then surprising that we are at present still unable to explain at all convincingly the much more complex phenomenon of switching in differently delayed conditioned reflexes? All we can say now (this should not, however, be regarded as our explanation of the phenomenon) is that in the switching of differently delayed conditioned reflexes, a tonic conditioned reflex is elaborated to those functional states of the elements of the conditioned reflex arc which are similar in sign and different in duration, and which are evoked by a moderate delay of reinforcement in chamber I and by a longer delay in chamber II, leading finally to different durations of the initial phase of inhibition of the conditioned reflex.

It goes without saying that the above diagrams, like the theories on which they are based, cannot be considered thoroughly substantiated by experimental data; so far they are only of a hypothetic nature. We believe nevertheless that at the present stage of research into this problem they appreciably facilitate the generalisation and interpretation

of the available experimental material and pave the way for its further experimental and theoretical elaboration.

In conclusion, I should like to touch upon one more question. Today we are inclined to believe that the presence of tonic conditioned reflexes is not peculiar to switching alone, but represents a universal phenomenon of higher nervous activity in general. Even under ordinary experimental conditions such factors as the moment when the animal is brought to the laboratory, the appearance of the experimenter, the placing of the animal in the chamber, the preparations for the experiment, the stable environmental elements in the chamber—all of these factors together represent a highly complex and linked tonic conditioned stimulus which activates the cortex in a specific way and creates in the cortex a stable conditioned-reflex background for subsequent phasic conditioned-reflex activity. In other words, the same process takes place here as in our experiments with elaborated switching under the action of specially selected switching agents. Amid the great diversity of inborn reflex activity of the nervous system, neurophysiologists long ago demonstrated the existence of two interconnected forms of this activity, namely, tonic reflexes and phasic reflexes, which have specific characteristics and are of definite significance for the various functions of the organism. In our opinion, there are at present sufficient grounds to assume that amid the great diversity of conditioned reflexes which constitute the higher or psychic activity of the system, there also exist both phasic and tonic conditioned reflexes which likewise have specific characteristics and are of definite signifcance for this activity.

Precisely in this light we consider our data in regard to switching, as well as our theories concerning tonic conditioned reflexes, as new corroboration of one of the fundamental principles of modern physiology which has been mentioned above, and according to which the laws governing the activity of various parts of the central nervous system have common biological roots. It is the principle which was characterised by Pavlov as the "natural community of basic relationships".

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BILATERAL REGULATION AS A MECHANISM OF BEHAVIOUR

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1

With the advent of cybernetics, the problems of the regulation of processes developing in various complex systems, biological included, have aroused far more interest than hitherto. Psychologists and physiologists already have some experience in the study of certain neuropsychic phenomena as *regulatory* factors, e.g., emotions in the general cycle of neurohumoral regulation, voluntary attention in the regulation of activity.

But emotional and voluntary processes are not the only bearers of regulatory functions. The effective regulation of actions requires a definite organisation of the sensory-perceptive and speech-thought processes. In this more general sense mental regulation of actions constitutes the basic problem of general and engineering psychology. As demonstrated by L. M. Wekker (47), comparative investigation of the features of such regulation and regulation in automatic devices, promotes the solution of problems involved in the modelling of human brain functions.

Analysis of the regulation of human behaviour calls for a broad psychoneurological approach conforming with the complex structure and dynamics of cerebral systems. Bearing this in mind, we shall examine some of the concepts of W. R. Ashby regarding the border problems of cybernetics and psychoneurology. Ashby works from the assumption that the brain displays all the features of a good regulator, including the ability to reduce the multiformity of outcomes. "The limit of this reduction is the regulation that holds the outcome rigorously constant" (13; 215). Such features are typical of human cerebral activity, thanks to which the reliability of information systems and the *stability* of regulation in man appear almost ideal from the engineer's standpoint. It should be borne

in mind that Ashby identifies bioregulation with homeostasis, which, actually presents but one of the diverse types of bioregulation. However, most important in the given context is Ashby's contention that homeostasis is not limited to regulation of the internal body environment as supposed by Shannon. Ashby sees homeostasis as a regulatory mechanism controlling the entire sphere of interaction between the body and the external environment. In this connection he remarks that "...there has yet to be written the book, much larger in size, that shall show how all the organism's exteriorly-directed activities—its 'higher' activities—are all similarly regulatory, i.e., homeostatic" (13, 195-96). But Pavlovian physiology has long since regarded the human body as a system distinguished by an extremely high level of self-regulation and has doubtlessly proved the regulatory nature of the processes of interaction between body and environment. Extremely expressive in this respect is the definition of self-regulation given by P. K. Anokhin as "a system of interaction under which deviation from norm itself provides a stimulus for return to normal" (12; 8). Doubtlessly, the principles of the reflex theory have proved most fertile in the study of bioregulation. The process known as switching or reversal, which E. A. Asratyan (15) has shown to be one of the major principles of conditioned-reflex activity, is, in particular, concerned with regulatory functions. The regulatory nature of higher nervous activity is inseparably bound with the entire process of reflection of the outer world in man's brain, with the entire process of his orientation in the environment. *Apparently, regulation and reflection are the two most closely related properties of human cerebral activity.*

It is the common nature of these two properties that offers the objective possibility for modelling various kinds of cerebral reflectory activity, thinking included, on the principles of amplification of regulation.

The fact that the human brain acts as a regulator of interrelationships between body and environment was borne in mind by W. Ashby when approaching the problem of modelling human thought processes. He perceived the further progress of technology and civilisation as a process of "amplification of regulators", which will immeasurably increase the power of cerebral mechanisms

concerned with the intake and sorting of information. Acting in this direction, he worked out his well-known "mental power amplifier", a special type of information machine which effects automatic data-processing by *amplifying the regulation* of processes involved in the accumulation and sorting of information (14).

Machines of this type should incorporate a governing principle similar to that of the mechanism of bioregulation, which Ashby defined as *step-type*. Every impulse, writes Ashby, as a step-type function within such a mechanism, "... *is* localised by its position in the sequence, but it has *no* localisation in any particular part of the column" (15; p. 124).

Ashby admits a certain degree of correlation between structure and dynamics only in the sense that "in a large polystable system the whole reaction will be based on activations that are both numerous and widely scattered" (15; p. 182), proceeding from the concepts of Lashley, who endeavoured to prove the equipotentiality of cortical elements. In Pavlov's theory of analysers, Ashby gives preference to the discovery of diffuse cells at the cerebral terminal of aech analyser, obviously underestimating the role of the *nuclear* cells concerned with the finer analysis of stimuli. Accordingly, in Ashby's view, the functional organisation of biological regulation is not determined by any definite structure, and the step-type nature of the mechanism of regulation is represented as a series of sequences in the circulation of impulses, i.e., as a purely temporary type of organisation.

In solving the problems involved in modelling man's cerebral activity, cybernetics may ignore both the amount of elements and the specific substance making up an organism or machine, but cannot neglect the *structure* of its regulation. This circumstance was specially emphasised by N. Wiener: "... Cybernetics takes the view that the structure of the machine or of the organism is an index of the performance that may be expected from it" (48; 67).

2

From the structural-dynamic standpoint, any biological system, including the human brain, may be regarded as a complex organisation of regulation circuits with a multi-

linked chain comprising the objects of regulation, measuring devices and servomechanisms, as well as feedback mechanisms ensuring the constancy of the regulated value. There is reason to believe that human cerebral activity incorporates all the types of feedback proper to living regulating systems. As demonstrated by A. D. Malinovsky, biological evolution was accompanied by the development of various types of feedback connections effecting the circuitary regulation of vital processes through the stabilisation of functions, ensuring their intensification, differentiation or departure from unfavourable conditions. Especially important is the combination of different types of intensification and stabilisation which helps to adjust the response thresholds of regulated organs (30; 169). Within the human brain, the various types of feedback act not only in series, but also simultaneously in different departments and at different levels of the CNS. In this regard it is important to note an essential distinction of biological systems as compared with automatic devices, which S. N. Braines characterised as follows: "One system of bioregulation may (and usually does) contain more than one circuit, including several doubles" (19; 146).

The doubling of regulation circuits in a single biological system is a phenomenon most typical of cerebral activity. It is in this light too that we should interpret the step-type nature of regulation mechanisms, since the doubling of regulation circuits at different levels of the CNS, particularly at the level of the brain stem with its reticular formation and the subcortical and cortical apparatus. It was no accident, therefore, that the idea of a multistorey hierarchic system acquired such prominence in the theory of bioregulation. This idea was developed by N. A. Bernstein, initially in his theory of regulation of movements, and later in his newly proposed conception of the physiology of activity (17; 129-130). The same idea forms the essence of the hypothesis put forward by S. N. Braines and V. B. Svechinsky about the three levels of biological regulation connected by definite subordinative relationships and concerned with the programming and regulation of internal body processes and its interaction with the external environment (19; 147-148).

The idea of a subordinated hierarchic system of bioregulation finds its peculiar implementation in a concept

according to which the brain does not participate wholly in regulation, but only through its specific regulatory structures which dominate over other, so-called operative structures. This concept is developed in Soviet literature by N. I. Grashchenkov, L. P. Latash and L. M. Feigenberg. They relegate to the regulating organs a variety of apparatus of different levels and origin, including the reticular formation of the brain stem, the non-specific thalamocortical projections, the cerebellum, the cortical and subcortical structures of the olfactory centre, the limbus corticalis, the anterior sections of the frontal lobes and certain other cortical structures.

It is admitted, however, that the division of cerebral structures into regulatory and operative cannot be too strict, since processes of self-regulation may likewise occur in the so-called operative sections. Therefore, in their general characterisation of bioregulation, these authors, too, put an accent on the "hierarchy of self-regulation processes" (25; 48) as a crucial feature, employing extremely expressive terminology in defining it.* They speak about the *vertical* organisation of any function in the nervous system. Such terminology, however, has found use in descriptions of more general systems of neurohumoral regulation, e.g., that of the blood sugar level. Such "vertical" subordination of the system of bioregulation is noted, e.g., by H. Drischel in a number of regulatory circuits, beginning with the homeostatic mechanism of the liver and ending with the cerebral cortex, which are linked up by direct and feedback connections through the insular apparatus of the pancreas and pituitary-diencephalic system (24; 82-84). The importance of the "vertical" or hierarchic organisation of regulation circuits increases in the course of biological evolution with the gradual cephalisation and corticalisation of nervous functions. Indeed, this vertical or multistorey hierarchic system of regulation is *basic* for the integrity of the organism and the unity of the processes of vital activity and behaviour.

It is sometimes held that complex acts of behaviour entail the obligatory circuitary circulation of information through all communication channels, involving all levels of the vertical system of regulation circuits.

* In Soviet cybernetics, the subject of the hierarchy of self-regulating systems was taken up by A. A. Lyapunov (29; 13-14).

The question arises, however, whether complex behavioural acts are possible without involvement of the entire multistorey hierarchy of regulation? Ashby believes such cases to be extremely widespread among the processes of interaction between the brain and the external environment. He considers it a paramount task of cybernetics to investigate the conditions under which individual subsystems in the unitary *polystable* system of the brain act with relative independence in their transactions with the external environment. In such cases, according to his view, a "supplementary regulation mechanism" comes into play, and "... coordination between parts can take place through the environment; communication within the nervous system is not always necessary" (15; p. 222). The most common model of this kind is the interaction of the arms in complex actions involving manipulations with various objects. As an example, Ashby analyses the cycle of actions of a tennis-player serving a ball. The movements of the right arm correspond to probable movements of the left, wherefore the "set" of the right arm is determined by a tentative forecast of the course of the ball's flight. Obviously, what Ashby means here is cerebral regulation of movements of the arms along contralateral paths, of which he makes special comment in the footnote: "We must avoid the tangles caused by the fact that the right arm is controlled by the left motor cortex, and vice versa" (15; p. 222). He thinks that the channel of communication between both arms (and both motor centres) "not only need not, ... usually does not ..." lie there (15; 221), indicating the central nervous system, i.e., the multistorey hierarchy of regulation. Undoubtedly, such facts must testify to the existence of a "supplementary regulation mechanism".

Ashby, however, confines his interpretation of bilateral connections to the popular pattern of contralateral connections between the hemispheres and motor organs, which may, to a certain extent, suffice for an understanding of the work of each hemisphere in isolation, but is decidedly inadequate for explaining their *permanent conjoint operation*.

Neurology knows multiform instances of the separate work of each hemisphere. But in these cases each of them acts only as the highest level of the multistorey hierarchy through which the circuitary circulation of information

and energy is effected, involving all links of the vertical organisation. It is known, for example, that when the cortex of one of the hemispheres is damaged or even removed, functional compensation is achieved by maximum activisation of all lower sections of the CNS, and not only of the apparatus of the intact hemisphere. But it is exactly these cases when there can be no talk of a "supplementary regulation mechanism", when the hemispheres organise complex behaviour with relative independence, without involving all links of the basic "vertical" organisation into the process of regulation. Such relative independence of the hemispheres is achieved by virtue of their permanent interaction, their conjoint, or, as Pavlov put it, "twin operation".

We believe that the essence of the supplementary regulation mechanism consists exactly in the *twin* operation of the hemispheres, which, naturally, involves the highest level of the vertical organisation of regulation.

At present cyberneticians, just as at one time neurophysiologists, obviously underestimate the *bilateral* structure of the brain and, consequently, the bilateral regulation of complex behavioural acts.

In Norbert Wiener's *Cybernetics*, one of the fundamental works on the subject, the concept of contralateral mechanisms of left- and right-handness employed by Ashby is also adopted as a point of departure. But Wiener goes farther in his conjectures on the nature and significance of this fact. He writes that "the cerebral functions are not distributed evenly over the two hemispheres and one of these, the dominant hemisphere, has the lion's share of the higher functions", "most of the 'higher' areas are confined to the dominant hemisphere" (30; p. 189).

Confronting the facts of domination of one hemisphere and the incidence of asymmetry in the human brain with the more equal development of the hemispheres in animals, N. Wiener comes to the conclusion that man's philogenetic development took the course of extreme specialisation, which, as we know from the general history of evolution, leads to the degeneration of a species. This is what Wiener has to say in this respect:

"In man, the gain achieved by the increase, in the size and complication of the brain, is partly nullified by the fact that less of the organ can be used effectively at one

time. It is interesting to reflect that we may be facing one of those limitations of nature, in which highly specialised organs reach a level of declining efficiency, and ultimately lead to the extinction of the species. The human brain may be as far along on its road to this destructive specialisation as the great nose and horns of the last of the titanotheres" (49, 191). We believe that the author's erroneous views on this issue follow from his use of the traditional neurologic pattern giving absolute significance to contralateral mechanisms of behaviour. For this reason, incidentally, Norbert Wiener contends that "now, the direct connectors between the hemispheres—the cerebral commissures—in a brain as large as that of man, are so few in number that they are of very little use; and the interhemispheric traffic must go by roundabout routes through the brain-stem" (49; 191).

It has already been noted that Ashby's attempt to find a "supplementary regulation mechanism" put him before a peculiar alternative: either the regulation circuits lie entirely "within" the central nervous system, or they must pass through the environment only. Neurological tenets, too, prevented Ashby from discerning the real nature of supplementary regulation.

Indeed, the vertical organisation cannot be correctly understood at all without a "supplementary" regulation mechanism, which constitutes not only a relatively independent entity in the general system of regulation, but also the most complex part of the multistorey hierarchy, namely, its higher level. This fact is likewise acknowledged by N. A. Bernstein, one of the founders of the theory of hierarchic subordination and bioregulation. In one of his recent works he wrote: "It can be said with certainty that the specific features of right-handness and its distinction from left-handness begin to be felt in movements and backgrounds which are the responsibility of this level. We would be going too far if we touched upon the problem of mirrored or synkinetic movements of both sides, etc. Here we must leave the floor to psychophysiologists" (17; 157).

Many years of psychophysiological investigations have left us convinced that it is exactly these bilateral connections at the highest level of the multistorey hierarchy of regulation that constitute the supplementary regulatory

mechanism. The regulation circuits at this level appear as extremely complex chains of recurrently and *bilaterally* connected links representing the general processes of vital activity and orientation in the surrounding world and the various forms of the latter's reflection in man.

The bilateral connections of the hemispheres include, of course, not only the interaction between symmetric sections of the hemispheres which are the cerebral terminals of analysers of the internal and external environment, but the entire system of regulation of receptors and effectors proper, which are also twin organs. Hence, the bilateral connections embrace a most complicated network of ipsilateral, contralateral and mixed relationships between twin receptors and effectors, on the one hand, and both hemispheres, on the other. We have grounds to regard bilateral connections also as the supreme manifestation of the general ("polystable") system of regulation and as a specific mechanism which may be defined as the *horizontal* regulation circuit supplementing the principal vertical hierarchic system of regulation. In the course of human evolution the supplementary regulation mechanism acquired increasing importance, the reason for which, in our view, is that the *progress of regulation is indissolubly bound with perfection of the processes of reflection and the body's active orientation in the external world*, particularly the reflection of space and time as the main forms of existence of matter.

3

More than ten years ago we published our work on *The Problems of the Twin Operation of the Cerebral Hemispheres in Pavlovian Theory and Its Relation to Psychology* (5) in which bilateral connections were regarded as a specific mechanism concerned with man's orientation in the surrounding world. During the intervening years a number of experimental studies have been made in our laboratories which allow the twin operation of both hemispheres to be viewed as one of the most important mechanisms of space perception (6, 7, 9, 10, 11). This conclusion was published in reviews of advances in Soviet psychology, being mentioned in papers on the theory of space perception (F. N. Shemyakin, 42) and the general theory of perception (P. A. Shevaryov, 43).

The latest researches in the evolutionary physiology of higher nervous activity in animals undertaken in laboratories headed by E. S. Airapetyants, permit us to link the mechanism of spatial orientation with the bilateral structure of the hemispheres, which is specific for the highest stage in the evolution of the brain (E. S. Airapetyants and V. L. Bianki, [3], [2]).

Interesting new data on the role of the conjoint work of the hemispheres in the spatial orientation of animals are cited by V. M. Mosidze (31). All this, in the aggregate, confirms our suggestion that the conjoint work of the hemispheres represents a special device by which the higher organisms adapt themselves to spatial conditions of existence (5; 190-91). According to our hypothesis, spatial orientation became the specific, perhaps even principal function of the developing twin sections of the brain. Whatever new functions may have been superimposed on the space-orientation function of conjoint hemispheric operation in the course of evolution, it remains a special function of the bilateral cerebral connections at the highest stages, including man. The evolution of adaptive activity was accompanied by progressive specialisation of animals' behaviour in regard to the spatial conditions of existence on earth. The objective nature of these conditions was such that through natural selection it promoted the gradual reinforcement of bilateral mechanisms producing images of environmental objects and determining the regulation of movements and the general orientation of animals in the external environment. This objective nature of spatial signals with which animals established progressively broadening nervous connections, is characterised by the following factors: the longitudinal extension of the habitation medium; *the three-dimensional character* of reflected objects presenting the animals' means of existence and hence the differentiation of depth; the *direction* of moving objects and the animals themselves in relation to the former, etc. Hence, decisive importance is acquired by the incompletely matched operation of twin receptors which are connected through afferent-efferent channels with either hemisphere by the contralateral, ipsilateral and mixed methods alternately, as, for example, in the visual and auditory systems. With such multiform bilateral connections, the impulses from homonymous receptors are trans-

mitted into both hemispheres, secondary analysis and synthesis being effected through the latters' *conjoint* operation. A consequence of mutual induction of nervous processes is the moderate disparateness in the images of individual objects and in the spatial field. This feature of bilateral afferent synthesis was of a paramount importance for the progressive development of *stereoscopicity* and *telescopicity* in the sensory functions. The construction of images of the spatial field and three-dimensional objects became more and more adequate with the development of the twin symmetrical structures of the brain known as hemispheres which gradually became the seat of all the higher functions.

The *bilateralisation* of nervous mechanisms appears as a biological process, intensifying with the *corticalisation* of neuropsychic functions. The latest evidence in favour of this view is furnished by the series of physiological and morphological researches carried out by V. L. Bianki in the laboratory of E. S. Airapetyants, which showed that the progressive development and increasing complexity of the hemispheres went parallel the growth of the commissures connecting both hemispheres into a unitary system. Extremely important testimony was furnished by the fine experiments of K. S. Abuladze who proved that the "entire reflex arc of the unconditioned salivary response lies on one side—the side of the salivary gland and receptor surface involved. In some cases the reflex arc of a conditioned salivary response lies in one hemisphere, and in others—in both" (1; 101). The bilateralisation of conditioned-reflex mechanisms as opposed to their unconditioned counterparts is a fact of major importance, genetically, no doubt, connected with the animal's orientation in space.

It is no accident that such binary effects as binocular vision, binaural hearing, bimanual tactile perception and dirhinic olfaction are among the most active and adequate forms of spatial perception.

Contemporary psychophysiological research has revealed the processiform and labile nature of various binary effects of every modality. The peculiar contradictory essence of all these effects is due to the fact that each of them originates and develops according to the laws of mutual induction of nervous processes which alternately irradiate through both hemispheres or concentrate in one of them.

It is this phasic alternation of mutual induction, each time altering the relationship between the hemispheres, that accounts for the phenomenon known as "conflict of fields" —visual, auditory or tactile. Thus, the binary effects demonstrate another major type of bilateral connections, vis., *lateral dominance*, i.e., functional asymmetry in the form of right-handness and left-handness. The numerous facts of functional asymmetry in various modalities which we investigated gave cause to believe that, similar to binary effects, functional asymmetry presents a mechanism of spatial orientation. Lateralisation, like binary effects, is a manifestation of bilateral connections. Left- or right-handness in motoricks, kinaesthetics, tactile sense, vision, audition and olfaction represent peculiar modifications of bilateral connections, which cannot be treated merely as an outcome of monolateral regulation of functions by one of the hemispheres, regardless of whether there is contralateral or ipsilateral regulation in the given type of afferent system.

Investigation of different types of bilateral connections allows us to contend that the special mechanisms of spatial orientation act in these connections as more general regulators of behaviour.

The earliest instance when we discovered such coincidence between the spatial-orienting and general regulatory functions of the bilateral cerebral system was when we studied the *transfer* of sensory and motor habits ensuring the *integrity* of the given form of behaviour. The most general mechanism of such transfer proved to involve definite bilateral connections usually taking part in acts of spatial orientation.

It was established, further, that bilateral connections have a major part to play in the systemic mechanism of time perception. This fact was revealed in our laboratory by M. A. Guzeva (1956) who investigated certain aspects of the differentiation of conditioned vascular responses to various signals (qualitative, quantitative, spatial and temporal). In these experiments, the vascular responses were registered in both hands, special attention being paid to the mutual conformity, i.e., symmetry or, inversely, asymmetry of their dynamics. Concomitance between the moment when the differentiation was perceived and the stage of vascular symmetry gave M. A. Guzeva cause to conclude that the "generalisation of stimuli is associated with

the unity and synchronous development of nervous processes in the hemispheres" (26; 11). The emergence of such synchronism as a temporal correspondence between processes in both hemispheres is probably connected with spatial correspondence, i.e., symmetry, which is *neurodynamically* unstable. Hence, synchronism is achieved through asynchronism, just as symmetry is through asymmetry within cerebral structures united by the mutual interhemispheric induction of nervous processes.

Some years later (in 1962) our co-worker V. P. Lisenkova staged another series of experiments in our laboratory, likewise taking plethysmograms of both hands. In all, the series comprised 183 experiments on 16 subjects (the number of presented stimuli totalling 2,257) Lisenkova showed that the hand-to-hand transfer of a conditioned vascular response to time signals begins with the very first combinations of conditioned and unconditioned stimuli and is observed throughout the experimental series, just as is the transfer of differentiation. Symmetric vasostrictor responses in both hands predominated during the formation of conditioned reflexes and differentiations, occurring in 81 per cent of cases.

At the same time, the responses displayed asymmetry in the intensity of the conditioned reflex, duration of the latent period and overall time of reaction. The percentage of responses asymmetric in these respects was 91.2, and of symmetric ones—only 8.8. As regards the latent period, asymmetric responses totalled 83.8, and symmetric reactions —16.2 per cent. The response time characteristics were similar, comprising 84.2 and 15.8 per cent respectively.

Lisenkova's experiments confirmed and modified our conclusion concerning the special role of conjoint hemispheric operation in the differentiation of time signals. It is noteworthy that quite recently D. G. Elkin also began to advocate the importance of conjoint hemispheric activity in the mechanism of time perception.

When analysing the plethysmograms obtained in Lisenkova's experiments, special attention was paid to the *regulatory* effects of bilateral connections on the vascular reactions of both hands. It was found that quantitative predominance in the intensity of the conditioned reflex, latent period and overall reaction time depended on the side where the reflex was *reinforced*. If it was reinforced

in the right hand, the intensity of the reflex and the latent period were greater in the *non-reinforced* left hand, and the time of reaction—in the reinforced right. Inversely, when the reflex was reinforced in the left hand, the intensity of the reflex and the latent period were greater in the non-reinforced right hand, and the overall reaction time—in the reinforced left. Regardless of the degree of motoric right- or left-handness, this peculiar equilibrium in bilateral connections was observed throughout. On the average, however, the value of the conditioned reflex transferred from the right hand to the left was greater than vice versa. This confirmed our own earlier findings on the hand-to-hand transfer of tactile sensory conditioned reflexes and the eye-to-eye transfer of a conditioned-reflex increase of visual acuity (5, 6, 10).

New data on the bilateral regulation of sensory processes were obtained in our laboratory by M. D. Alexandrova in experiments dealing with the chromatic boundaries of monocular fields of vision (4) and by Y. F. Rybalko who investigated the dynamics of functional asymmetry in the fields of vision (38).

Sensory and vascular reactions evince common features of bilateral regulation. Comparative data on sensory processes of different modalities as well as vascular and motor responses (to be described further) gave us grounds to contend that bilateral connections are widespread, occurring "in many instances of regulation of vital processes and behaviour in man" (11; 14).

Bilateral connections are characterised not only by *subordinative* relationships between doubles, which we mentioned in describing the vertical organisation of regulatory circuits, but, to a still greater extent, by coordination between such doubling circuits, which enhances the conservation and reproduction of energy needed for the functioning of twin structures. Such coordination of bilateral connections was first revealed by I. M. Sechenov in his ergographic experiments. At the moment when one hand was engaged in work, the other was in a state of active repose, i.e., restoring its muscular energy. Sechenov (39, 40) interpreted this as a manifestation of peculiar energy balance occurring in the process of interaction between symmetrically localised nerve centres. Sechenov's findings have been repeatedly confirmed by modern physiology and

psychology, but are interpreted merely as one of the possible manifestations of the general law of induction of nervous processes. As regards ourselves, we believe Sechenov's interpretation to be more general and hence more acceptable for modern biophysics.

In our laboratory, K. D. Shafranskaya repeated Sechenov's ergographic experiment as part of a special investigation concerning the effect of the work of one hand on the working capacity of the other, taking into account the incidence of right- or left-handness. Regardless of the effects of the last-named factor, the hand beginning to work later always evinced a higher capacity than the hand starting first. The "second" hand was always more efficient, no matter whether the work was begun with the left or right hand and whether the man was right-handed or left-handed. Only after making this general conclusion, Shafranskaya remarked that the right hand was always somewhat more efficient as a "second".

Shafranskaya experimented with alternately working hands, owing to which the phases of mutual induction came on rather slowly. A different experimental pattern was followed by our collaborator N. A. Rose, who investigated the interaction of the hands in certain work-acts involving the use of remote controls (37). When both hands manipulated simultaneously, various types of micromovements (motion and repose) were distributed more or less equally between both hands. So, for example, in manipulations with the so-called "beak", 467 moments of movement and repose were recorded in 3.5 seconds, out of which 233 fell to the right hand and 234 to the left. The described mobile relationship between moments of movement and repose testifies to the existence of bilateral balance in simultaneous bimanual operation, occurring throughout the work-process not only between the unitary coordinate systems of both hands, but even between homonymous fingers. Manipulations like these clearly demonstrate the role of feedback connections as channels of information utilised to regulate and correct work-acts. Consequently, the motor sphere, where fixed dominance (right- or left-handness) plays an important part, is subject to the same law of *coordinative* relationships as characteristic of the bilateral connections acting in sensory and vascular processes. More profound investigation of these processes will

help to clarify the informational and energetic aspects of behavioural regulation. The dominance of one of the hemispheres during their conjoint work is always concretely conditioned by the situation and the structure of the activity in hand, and may alternately be predominantly informational or energetic. This proposition is based on our many years' experience in the psychophysiological investigation of functional asymmetry.

The latest electrophysiological findings confirm our views. So, for example, F. N. Serkov and R. F. Makulkin came to conclude that the "hemispheres have a permanent desynchronising, i.e., tonic influence on each other" (41; 217).

In 1958 the Czechoslovak physiologists J. Bureš, and Burešová published an original work on conditioned reflexes in which they had utilised irradiating cortical inhibition. One of the results was to prove that "lateralisation represents a conditioned reflex with a clearly outlined efferent cortical field" (20; 335).

Lateralisation appears as an effect of the regulation of bioelectrical activity in *both* hemispheres. The latest electrophysiological findings confirm our surmise concerning the regulatory significance of bilateral connections which manifest themselves in the dynamic organisation of man's sensory, motor and vascular reactions to environmental changes. It is possible that this regulatory function, closely associated with the maintenance of optimum levels of cerebral reflectory activity, will provide the answer to the question posed in 1923 by Pavlov: "How is the simultaneous activity of the hemispheres to be understood and explained? What, in it, is intended to be substitutable, and what advantage or superfluity is involved in the constant united activity of both hemispheres?" (35; 8).

We believe that this activity has regulatory significance. Besides ensuring a certain stability of behaviour, it provides the possibility of switching over symmetrical organs in strict accordance with the spatial localisation of external signals. More than ten years ago we arrived at the conclusion that "readjustment of relationships between both hemispheres is conditioned by changes in the external environment" (5; 192). To substantiate this, we cited experimental data testifying to changes in the extent of lateralisation in the work of twin organs (visual, auditory, tactile,

kinaesthetic, vibrational, olfactory), depending on changes of spatial conditions. Subsequently, similar phenomena were discovered in the vascular and muscular-motor systems, which include twin organs. The varying degree of lateralisation of one and the same function in the same individual testifies to a changing degree of dominance of one of the hemispheres in the combined work of both. This fact is confirmed by the latest findings of the Czechoslovak scientist J. Černáček who in 1959-61 elaborated a method for quantitative assessment of the degree of motor domination. By employing 17 different tests for actions of varying complexity, he determined the index of such domination as a quantitative expression of left- or right-handness. The data were plotted on Gauss' curve whose peak revealed a slight deflection towards right-handness, most of the subjects turning out to be "moderately right-handed individuals" (22), (21; 559).

Variations in the degree of domination were investigated in our laboratory by G. P. Pozdnova who studied the development of manual kinaesthesia in schoolchildren during handicraft training. As compared with the first form, second form pupils showed greater variations between the kinaesthetic characteristics of the right and left hands. However, as Pozdnova remarks, "third form pupils showed a greater precision of movements with the right hand than with the left, but the difference between the right and left hand was far less marked than in the first and second form".

The right hand of a third form pupil differs but little from that of a second form pupil, the variation in the precision of its movements reaching only 1.7 mm. But the precision of a third form pupil's left hand movements is 5.6 mm greater (36; 263). In graphic acts (writing or drawing) dextrolateral domination is more stable than in work-operations conducive to a greater correlation in the actions of both hands, and hence, as Pozdnova's experiments showed, to a more stable development of the left hand in right-handed subjects. Naturally, the dextrosinistral index in this case shows notable changes. Still greater changes in the degree of domination appear during the transition from working to gnostic movements of the hands (palpation of objects in the process of active tactile investigation). An earlier series of our own established that the

left hand of many motor right-handers proved dominant in tactile sensitivity (8).

Of considerable interest in this respect are the latest findings of American researchers (Semmens, Weinstein, Gantt and Teuber, 1960) who investigated derangements of tactile sensitivity in man after gun wounds of the left and right hemispheres. They revealed a bilateral, but essentially different cerebral representation of the manual tactile functions. In the left hemisphere these functions are differentiated, while in the right they are represented more diffusely. It is on the background of bilateral regulation of sensomotor and speech activity that the left hemisphere effects its dominant function. The varying differentiation of the hemispheres, states A. R. Luria, manifests itself in the dynamics of functional systems even in cases when symmetrical areas are morphologically identical (28). Asymmetric functioning of symmetric cerebral structures is an extremely widespread phenomenon which may be explained by the laws of mutual induction of nervous processes. Doubtlessly, however, there also exist asymmetric structures, speech and motor in particular, which operate relatively symmetrically owing to synchronisation of the processes concerned.

Bilateral regulation as a mechanism of behaviour incorporates both mentioned structural-dynamic characteristics of the hemispheres (symmetry and asymmetry). Such regulation is effected by the switching of twin doubling organs (receptors, effectors and their cerebral regulators) from symmetry to asymmetry and vice versa. Accordingly, J. Loeb, who held symmetry to be a universal principle, came to assert the complete identity of symmetrical points of the body surface, muscular system and receptors in man and animals as regards chemical structure and reacting masses (50; 27). Despite this fallacy, it would be wrong to discount Loeb's priority in posing the very problem of bilateral regulation of behaviour and of the factor of symmetry as a geometric law to be extended also to the structure of all living bodies. He first drew attention to the replacement of radial by bilateral symmetry in the course of biological evolution, though failing to explain the causes of these radical changes in the geometry of living bodies.

Loeb was among the first naturalists to formulate the idea of the community not only of physicochemical, but of

geometric laws in organic and inorganic nature, alluding to the symmetry of body structure. Asymmetry, however, which P. Curie preferred to call dissymmetry, is equally universal in nature. As we know, V. N. Vernadsky, the founder of biogeochemistry, considered L. Pasteur and P. Curie to be the originators of the theory of dextrality and sinistrality in nature. Vernadsky himself came to the conclusion that "we can regard dextrality-sinistrality as an extremely sensitive indicator of the physical state of space" (46; 5). According to Vernadsky, dextrality-sinistrality as a universal geometric property of space manifests itself "alike in energy processes and actual physical vacuum" (46; 11). A. I. Oparin, too, wrote about the special significance of asymmetry in the biochemical evolution of life (34).

An important addition to the earlier ideas of A. V. Shubnikov about the universal scope of symmetry in living and non-living nature (44) is his recent statement that "dissymmetry is a widespread feature of living nature" (45; 11-12), particularly as regards the human body and man-made domestic and working implements. Among the relevant factors he indicates the dissymmetrising effects of cosmic forces, as was surmised by L. Pasteur. An example of such effects are the respective dextrality and sinistrality in the height of riverbanks in the Northern and Southern Hemispheres of the globe. The dissymmetrising factor in this instance is the "asymmetric combination of two mutually perpendicular forces—the component of the gravity of moving water streams and Coriolis's force" (45; 20).

In the view of B. V. Ognev, the same factors account for bilateral asymmetry in man and animals. In 1955 he wrote that "the greater development of the right half of the body in man, animals and birds is explained, to our mind, by Coriolis's acceleration of the rotation of the Earth" (33; 36). For the Southern Hemisphere, according to this view, the effect is reversed, i.e., there is a greater development of the left side of the body or, at any rate, a widespread incidence of ambidexters. By B. V. Ognev's estimates, the number of left-handed individuals in the Soviet Union ought to reach several million, and for the entire globe—tens of millions (33; 34).

However, the latest American estimates raise this figure to 200,000,000 people. The majority, despite their natu-

ral giftedness, are in less favourable conditions than right-handers, since all tools, domestic appliances and implements of art are designed for manipulation with the right hand. For this reason the Americans have begun designing tools and other implements oriented in the direction of the movement of the left hand to raise the efficiency of left-handed people.

Nino Lo Bello remarks in this respect that it is not left-handers who should be adapted to right-handed technological standards but, conversely, technology and its standards should be readjusted for left-handed individuals (32). This idea, not without its serious foundations, is however exploited in the general spirit of private enterprise to publicise the manufacture and sale of articles for left-handers as a new field.

The question of the expediency of retraining left-handers for work with the right hand is again being discussed in modern scientific literature. Such readjustment is held to be fraught with the hazard of retarded development, since motor left-handness involves a wide range of intellectual and personal qualities, as demonstrated, for example, in a study by M. Clark on 300 children (23).

In Soviet medical literature, compulsory early-age readjustment of left-handers for right-hand work has been opposed by Ognev in accordance with his general standpoint based on the assumption of linkage between the hereditary-conditioned notion of asymmetry and universal laws of nature. Social influences are regarded by Ognev as a secondary factor. It may be presumed, however, that the asymmetry of the human brain owes its origin to labour, social evolution and the specific influence of speech. Moreover, such asymmetry serves to complement the symmetry of the hemispheres, as is the case in many other natural phenomena. Ognev considers the concomitance of symmetry and asymmetry to be a manifestation of the law of unity of opposites. We believe that mutually opposing forms of asymmetry itself may be concomitant as well. One of the most striking instances of this is the existence of ambidextrality in a single individual, manifest in the working movements of the hands and the work of the motor-supportive apparatus.

Such coincidence was noted by V. N. Zhedenov who observed that a greater development of the right hand is

mostly (in 70 per cent of cases) coupled with stronger development of the left leg, which is highly characteristic of typical right-handers (50; 54). In right-handers, accordingly, it is not the left but the right hemisphere that plays a leading role in the regulation of energy streams participating in the organisation of motor-supportive functions.

Thus, the hemispheres form a bilateral system or regulation of the processes of vital activity and behaviour. This system regulates the numerous streams of information and energy, apparently, in such a manner that at each given moment in the conjoint work of the brain one of the hemispheres acts predominantly as an information regulator and the other as a regulator of energy. Both hemispheres are peculiarly dominant, each in a specific sphere of regulation. The switching, storage and reproduction of the resources of neuropsychic development is, to a considerable extent, ensured by bilateral regulation as a mechanism of behaviour.

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SOME PROBLEMS ON THE CONTROL OF MOTOR ACTS

By N. A. BERNSTEIN

The struggle for the recognition of the biological significance, reality and universality of the principle of cyclic conrol of vital processes is now a thing of the past. As it often happens when scientific conceptions undergo sudden changes new ideas and genial foresight are now discovered in the works of the old classics of physiology (Bell, Sechenov, Jackson) and those nearer to our days (Ukhtomsky [16], Wagner [18]). As regards the coordination of movements, the author of this article described the general mechanical basis of the principle in 1929 (2) and expressed it in the general form of a differential equation (3), (4) in 1935. What then involved a bitter struggle is generally recognised now. At present the principle is being extensively developed, elaborated and tried on heuristic models and automatic devices for many diverse fields of practical application. The time is now ripe to take a further step forward and to formulate the new problems in this field. at the same time focusing attention on a few aspects of the circular principle of control, which have hitherto received insufficient attention. Facts from the physiology of motor acts are suitable material for both these tasks.

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The enormous biological importance of the motor activity of organisms is obvious—it is the almost exclusive form by which the organism interacts with the external environment, actively acts on it and effects changes in it. changes far from indifferent to the organism. It is therefore particularly difficult to understand why the theoretical aspect of the physiology of movement has received less attention than the study of receptor mechanisms or the

physiology of internal processes. In manuals on physiology locomotion is disregarded and very little, if any, space is allotted to it. It should be worthwhile to show how great a loss to general physiology this disregard has incurred.

If we classify bodily movements according to the biological significance they have for the organism, first-rank importance should obviously be ascribed to those activities, which solve a motor task. Without going into an analysis of this conception at this stage, let us point out that the significant problems to be solved by a motor act generally originate in the external world surrounding the organism. This definition immediately puts all "idle" movements, those not connected with the overcoming of external forces, and also the bulk of instantaneous, single-phase movements, such as pain reflexes (the jerking back of the paw), etc., outside the scope of significant acts. This shows that laboratory physiology, which with few exceptions refused to deal with other movements than pain, defence, and at the most scratching reflexes* has impoverished its store of knowledge not only quantitatively but also qualitatively and, as we shall prove, even in problems not connected with movement proper.

First of all, if we must have mechanical and biomechanical data on "idle" actions (pointing, drawing lines in the air, etc.) to discover the circular sensory control, this necessity is self-evident in the case of motor activity connected with overcoming external forces. No matter whether the task consists in locomotion (especially a complicated motion, such as running on uneven ground, hurdle jumping, swimming through waves, etc.), in the struggle with another animal, or work done by a human, the condition common to all of them is that the movement must master forces which are not under the control of the individual, are unforeseen and therefore cannot be overcome by a stereotyped movement, controlled only from within. A careless rejection of this active interaction with an environment not subject to the control of the individual (the confinement to bare "atoms of motion" was justifiable for the mechanicalists—the atomists of the past century, who always considered that the whole is nothing but the sum

* The reaction known as the orienting reflex was referred to this category only terminologically, and, as far as is known to the author, has never been used for immediate research into reflex activity.

of its parts) resulted notably in the disregard, until recently, of the principle of sensory feedback, which could have been easily discovered in moving objects and scientifically explained as long as a hundred years ago.

The principle of the open reflex arc was for many years the leading and universal principle in physiology. We must not exclude the possibility that in elementary processes, such as the salivary reflex, or generally in abrupt motions secondary as regards their biological importance, such as the jerking back of the paw in pain, etc., the arc does not close to form a reflex circle typical for the scheme of a controlled process. It is also possible and even likely that due to the abruptness or elementariness of these acts, the cyclic structure passed unnoticed and was not registered (for the salivation process this is almost doubtless). In any case it seems extremely likely that the reflex according to the arc scheme is only a rudiment or a very particular case of physiological reaction.*

Last but not least there is one more loss physiology has suffered by substituting for real motor acts, which solve an arisen objective problem, fragments of motion of an almost artifactual character. This loss has until now not been sufficiently realised even though it has impoverished our knowledge in receptor physiology and become responsible for important methodological errors.

It must be noted that afferent systems in higher animals and in man in the role of receptors of starting signals, "turning on" a reflex arc—the only role studied by physiologists of the classical school—function differently as regards the nature of their action and its quality from tracing and correcting instruments during the performance of motor acts. This difference becomes clear when once again from the vantage point of biological significance, we pay attention to the properties which both in the former and in the latter function had to be chosen by natural selection. The receptor must possess a high sensitivity to be able to fulfil the starting-signal function, i.e., must possess an extremely low threshold both with respect to the absolute force of the signal and the ability to

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* I should be reluctant to even exclude the possibility that the first reflex to ever take the scheme of an open arc made its appearance where the first "elementary sensation" in the world emerged—and that both emerged in laboratory conditions.

differentiate between signals. Of primary biological importance are the teleoceptors: smell, hearing (also ultrahearing) and vision—having different rank-orders in different types of animals. To separate significant signals from the chaos of "noise" there must be an analytical or analysing ability in the receptor apparatus of the central nervous system (it is only natural that Pavlov who has done so much to deepen our knowledge about the starting-signal functions of the receptors, named them analysers, defining them as "synthetic" only in the last years of his life). Finally, the most important mechanism for this starting-signal role, foreseen by Sechenov (14) and experimentally proved by foreign researchers (who based their observations on practical tasks concerned with military scanning), is the aggregate of processes entering the active systematic search or "scanning" by each teleoceptor of its range. These processes are completely active, using the effector mechanism just like the latter uses afferentation in the control of movement but, let us get that clear from the very start, have nothing in common with processes utilising organised motor acts for the entire active perception of the objects of the outer world, as described in greater detail further in the article.

When the voluntary movement has been "turned on" by a sensory signal, biological expediency poses to it entirely different demands. This has resulted in the formation in the phylogenesis of mechanisms of circular sensory correction. No matter of what nature the motor task and the external object at which the act is directed, the correct realisation of a task which is useful for the individual presupposes a maximally complete and objective perception both of the object and of every consecutive phase and detail of the individual's own actions directed at the solution of the task. The first of the properties of the receptor apparatus in the described role—its completeness or synthetic property—is ensured by the sensory syntheses (or sensory fields) which have been thoroughly studied by psycho- and neurophysiologists. They include, for example, the scheme of the individual's own body, the space-motion field, the syntheses of objective or "qualitative" (topological) space, etc. I have attempted to show the role of these "fields" in the control of motor acts in my book on the construction of movement (6). Suffice it to remember that

1) in this functional field the synthetic property in the operation of the receptor apparatus is not purely declarative (as it was above) but has actually been observed as the main fact in motion, both in the normal and pathological state, and 2) that in every one of these sensory syntheses, ensuring the processual control of motor acts, the structural scheme, combining the activities of different, proprio-, tango- and teleoceptors has its specific properties, differing in quality and quantity. The confluence of the elementary informations flowing to the central synthetising apparatus from the peripheral receptors is so deep and strong in this case that it is generally almost impossible to divide them by self-observation. In the described function all or nearly all types of receptors (except taste, maybe), are taking part, but in very different orders of ranking. Of first-rank importance is the wide system of proprioceptors (in the narrow sense); next all the tango- and teleoceptor apparatus set in, being organised on the basis of all preceding practical experience and playing the role of the "functional proprioceptor apparatus". Other purely physiological features in the operation of receptors, when these function in the described role—the parameters of adaptation, the thresholds of "comparison", the functioning frequency, etc., will be discussed in the second part of this article.

The other of the above-mentioned determining features of the receptor mechanism as a participant in the circular coordination process—objectivity—is of fundamental importance, and it is therefore necessary to treat it in greater detail.

In the signalling (starting or inhibiting) role, the only one that could be noticed when reflexes of an open arc scheme were analysed and which resulted in the whole set of perceptory organs in the central nervous system being styled the "signal system", the afferent function is not required to deliver objectively correct information. The reflectory system will work correctly if every effector reply will have its own established a) constantly invariable and b) unmistakably recognisable starting-signal code. The content of this code can be entirely conditional, and this will not create any interference with the functioning of the system, if the two above premises are present. That this indifference of the central nervous system to the semantic content of the signal is not a strange and exclusively

biological phenomenon, but is inherent in the nature of the starting-signal function, is best proved by the fact that such conditioned coded signals faultlessly effect all necessary switchings-in and switching-overs in telecontrolled automata. We can build two identical engines, steering mechanisms, radio-relay schemes, etc., and without introducing differences in design, arrange that on feeding in radio codes A, B, C, D the first will respond by reactions 1, 2, 3, 4; the second by 4, 2, 1, 3 (or any other).

In solving a motor task the receptory system operates in an entirely different manner in the control and coordination function. Here the degree of the objective correctness of the information determines the success or failure of the action. In the whole course of the phylogenesis of animal organisms, natural selection has inexorably eliminated the individuals whose receptors worked like distorting mirrors, when servicing their motor functions. In the course of the ontogenesis every clash of the individual with the ambient world, calling for the solution of a problem in motion has, often at supreme cost, forced the individual to work out in its nervous system an increasingly correct and exact objective reflection of the outer world in the perception and comprehension of the situation forcing it to act, and also in projecting and controlling the realisation of that action, in a manner adequate to the given situation. Every meaningful motor act, on the one hand, requires not a conditionally coded, but an objective, qualitatively and quantitatively correct reflection of the ambient world in the brain, and on the other hand, is an active instrument for the correct cognition of the surrounding world. The success or failure in solving every actively experienced motor task results in the progressive refinement and cross-referential check of the indications of the above-mentioned sensory syntheses and their components,* and also to the cognition through action, testing by practice, which is the corner-stone of all dialectic materialistic theory of cognition, and in the case here

* The indubitable fact of the coexistence in man's central nervous system of several qualitatively different sensory syntheses does not contradict the statement about the objectivity of brain reflections is explained to a sufficient degree by the physiology of the coordination of movements.

investigated serves as a sort of biological context to Lenin's theory of reflection.*

The comparison made on the preceding pages between the two manners in which the receptor systems act, so unequal as regards their date of discovery by science and the extent to which they have been studied, will enable us to deal in a new way with some of the features peculiar to the mechanism of the "classical" signalling processes for the "turning on" and differential inhibitioning of reflectory reactions.

Long before telemechanics confirmed the essentially fundamental conditional nature** of starting or switching codes, Pavlov established this biologically. It was soon universally accepted that any perceptible stimulus can easily be transformed into a starting signal for an organic reflex. Later works of the Pavlov school (Speransky [15]), showed that in the whole aggregate of physiological functions, including the seemingly inaccessible deep hormonal or cell-metabolic processes, there is no single act which could not be connected by fundamentally identical methods with any starting stimulus. This wonderful indifference of the nervous systems to the content and quality of starting stimuli was noted by Pavlov in his initial studies. This is proved also by the designation he gave to impulses artificially inculcated to stems of old organic reflexes, namely conditioned stimuli. The name proposed by V. M. Bekhterev (9)—combined stimuli-reflexes—is less profound as regards the internal sense of the phenomena, but more in conformance with the diagram of their mechanisms, which by now has become quite clear.

To transform any agent lying above the threshold into a conditioned starting stimulus for an organic reflex two

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* The mastery of nature manifested in human practice is a result of an objectively correct reflection within the human head of the phenomena and processes of nature, and is proof of the fact that this reflection (within the limits of what is revealed by practice) is objective, absolute, eternal truth (11).

** Even though the conditional nature in the aspect discussed does not call for objectivity, it does not exclude nor contradict it. Besides, in this article the contraposition and delimitation between the starting-signal and correlation functions of the receptors has been stressed more sharply and alternatively than is true of physiological reality, where the two types of functions can coincide in time or one can grow into the other.

conditions are essential 1) the primary—there must be a coincidence or combination within a small interval of time of the agent with the realisation of the given reflex and 2) the secondary—there must be a certain number of repetitions of these combinations. The first of the two conditions refers the phenomenon to the cycle of associations by contiguity and is characterised by indifference to the meaning of the associated notions or receptions. It is interesting to note that to transform an indifferent stimulus into a conditioned starting stimulus it is essential to combine it with the effector part of the unconditioned reflex, but not with the afferent one, which is mobilised in the standard test only as a means to bring about the operation of the effector semi-arc. This is proved, for example, by the fact that conditioned reflexes of the second order can be brought into play when an indifferent stimulus acquires the property to act as a starting stimulus for this reflex, even though the effector part of the reflex is put into action not by an unconditioned but by a conditioned stimulus of the first order, previously imparted to the reflex. Another proof is that the methods used to train animals provide for the giving of food to the animal as an incentive (i.e., reinforcement by an "unconditioned" afferent impulse) after the animal has correctly carried out the required action, according to a relevant conditioned command, and this feeding does not act as an unconditioned starting stimulus for the action being taught. This formerly underestimated particular deserves attention in this context because the formation of the associative link in the brain between the conditioned afferent process and the effector part of the reflex, we think, can be explained only if this effector realisation of the reflex is reflected (once again according to circular feedback) back into the central nervous system and can be associated with the afferent process of conditioned stimulation. This could serve as a further confirmation of the fact that recurrent afferent acts, as direct participants of the process, are present also in classic "arc" reflexes, even though they have as yet escaped notice.

The other condition for the formation of a conditioned link, the one we called secondary, namely, the necessity for a certain number of repeated combinations would be

difficult to explain other than as a requirement to enable the individual under experiment to segregate from the chaos of irritations he is bombarded with from the outside the new reception being imparted to him. The number of repetitions must be sufficient for the individual to determine that the coincidence in time of the intero- or proprioceptions of the reflex being realised with this particular element in the whole aggregate of exteroceptions is not accidental. It may be difficult and take a comparatively long time to establish the required and sufficient number of repetitions for a semantically indifferent stimulus because it may not attract the interest and attention of the individual ("orienting reaction"). The old conception of naive materialists about the gradually "opened" paths (Bahnung) or synaptic barriers in the central nervous system can now be considered as belonging in the dust-covered archives of science.*

It may be worthwhile to say a few words about a fact, which in the light of the new discoveries of regulatory physiology, still remains unclear. The structure of almost all studied conditioned combinations is such that a new conditioned afferent starting stimulus is imparted to the organic unconditioned effector semi-arc. The diversity of the unconditioned effector processes and of the afferent "signals" which can be tied up with them is unlimited; but not a single case is known of a reverse structure of a conditioned connection, i.e., the attachment of a new conditioned effector terminus to an unconditioned afferent semi-arc. A certain manifestation of this reverse type was observed in the experiments made by Yerofeyeva long ago, but Pavlov describing them in his *Lectures on the Work of the Cerebral Hemispheres* (13; 43-45) adds a number of limitations and reservations. No matter how this "structural paradox" will be explained in future, it is obvious that the

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* If some indifferent reception again and again and without intermission coincides in time with some unconditioned process, say the interoception of salivation, etc., the so-called *a posteriori* probability that such coincidence is not accidental grows rapidly by itself and after some ten repetitions differs little from unity. But to form a link it is also necessary that the indifferent stimulus and the fact that both stimuli are constantly present attract attention, i.e., there must be active reception by the individual.

inertial constancy of the effector semi-arc of actually practicable conditioned motor reflexes makes it extremely difficult to use their structural mechanism for the teaching of unfamiliar movements, for the formation and perfection of motor habits and skills, etc.

We think that an investigation of signal codes in their combining role made in the aspect of regulatory physiology should be able to throw new light on questions pertaining to the second signal system. From the above, it is clear that since there may be an unlimited number of conditioned signalling codes, speech phonemes may enter their number, without forming a class of their own, provided that they, like all other stimuli that can be used as signals, are perceptible and distinguishable. Nobody ever ascribed a second signal system or architectonic fields, homological with the field of Wernike in man to dogs, bears, seals or cats; yet any one of these animals (not even being "higher" mammals) is trained to react to word signals with the same ease with which they form conditioned links and differentiations in response to other stimuli. These phonematic signal codes, not differing essentially from other codes, may genetically have been embryos of phoneme-orders with primeval man, a sort of rudimentary imperative mood from which eventually the speech forms of verbs evolved.* On the other hand, the designative elements of speech, from which the category of names evolved, never could have had a signalling function in the above sense. The interpretation of the "second signal system" as the verbal reflection of objects (and generally of the primary receptions of external objects, forming according to this conception in their aggregate the "first signal system") which is reflected in the vocabulary used in experiments on the "verbo-motor method", is the result of a confusion of two distinctly different physiological functions and speech categories. Words

* The author wishes to make the following reservations: 1) this is not an attempt to solve the chronological order in which verbal and nominative categories of speech could develop with primeval men and 2) no account has been taken of the linguistic phenomenon well-known to scholars of primitive languages, namely, the secondary acquisition of starting signal function by nominative elements.

as signals do not form a special system and in the form of starting phonemes are fully accessible to animals, who are still far from possessing the function of speech. Words and speech as the reflection of the extraneous world in its static state (names) and dynamics of action and interaction with the subject (verbs, opinions) really do form a system, accessible and peculiar only to man; but to designate speech that has reached this stage of importance and development as a signal system means to consider only one of the most rudimentary and least important of its manifestations.*

The idea of a second signal system undoubtedly was one of the consequences of the above-mentioned methodological abuse inflicted to physiology because it recognised only the starting signal role of the receptor apparatus and underestimated its principal biological and social functions: cognition through action and the control of the active influence on the surrounding world. Some drew a line between "reception" and "signal" and referred the percepted word to the category of signals; but at the same time some could not ignore the enormous qualitative oddity of speech as a symbolic reflection of the world perceived by *homo sapiens* and of himself in that world. The tolerance for the atomism mentioned above made it easy for them to pass by the structural features of speech (making it not a collection of words, but an instrument of thought) and to interpret it as a sum of word-signals, predominantly of a concrete meaning.

Soviet physiology avoided another and much more important gnosiological pitfall, into which many thinkers of the Western world fell and which also arises out of the one-sided interpretation of the receptor function—from the undoubted fact that the irreproachable functioning of the reflectory apparatus is reconcilable with the complete conditionality of the sensory codes causing them it is easy to slip into the erroneous view that all receptions have a symbolic importance, that the image of the world in the

* It should be added that the building of an automaton-robot able to understand speech is a hopeless task at the present level of technological development. A robot, however, able to differentiate and react to several vocal phonemes could be built without special difficulty.

brain and psyche is conditioned, that objective reality is unknowable and into other idealistic conceptions, long since refuted by genuine science.

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Let us now make a detailed analysis of the mechanism of the motor coordination in higher organisms, attempting to solve two tasks: 1) to draw from this analysis the maximum amount of information accessible at present on the general laws governing the control mechanisms and 2) to try to discover wherein lies the peculiarity of the motor functions in higher animals and particularly in man, which differs drastically in action and resources from everything we can expect from automation techniques of today, and probably of tomorrow. I shall have to touch upon many subjects which have been thoroughly analysed at an earlier date (6), (7); so, in order to avoid repetitions I shall treat them in this article as concisely as possible, and only insofar as they are necessary to pursue a logical line of thought, referring the reader interested in particulars to the cited treatises. An attempt has been made here to add to and deal more fundamentally with these problems, emphasising mainly the fundamental mechanisms of the coordination control system, and to correct errors which have by now become apparent.

The first biomechanical difference of the motorium of man and higher animals from any man-made automatic device, one I have repeatedly stressed, consists in the enormous degrees of freedom (expressed in three-place figures) the motor apparatus disposes of kinematically (depending on the many links in its freely connected kinematic chains) and elastically (due to the elasticity of the moving rods—the muscles and the absence because of it of simple relations between the measure of the activity of the muscle, its tension, length and the velocity with which it changes). Let us dwell on two examples to convince ourselves how greatly every additional degree of freedom complicates the control of movement.

A vessel laying its course on the sea has three degrees of freedom (if we disregard roll) but for practical purposes it suffices to control only one degree—the direction or course, since a vessel that has deviated from its course

on the vast sea does not have to return to its initial course and can continue a course parallel but removed from the initial one by a few cable's lengths. This task can be successfully carried out by a compass autopilot. Let us now imagine an automobile which has to travel along a highway of a limited width, automatically negotiating all the curves and turns of the highway. Here two degrees of freedom of movement have to be controlled. An analysis, however, shows that no matter what method is used to feed to the automobile information about the course of the highway (its centre line, for example), no matter whether it will be received by photo-, electro-, or mechanical receptors, etc., the block diagram of such an automatic steering gear, able to drive the car over turns on the highway and holding it close to the centre line must contain 1) a distance receptor to detect deviations from the line, giving the sign (+ or —); 2) a receptor to note the angle formed by the axis of the car and the centre line with its sign; 3) a receptor of the actual curvature of the road; 4) a summation shifter and 5) a system of regulators to erase parasitical "stagger" of the machine to either side of the course. This shows how many complications arise out of adding a single degree of freedom. As far as I know, no such robot has yet been built. It should also be useful to note that the enormous difficulty of building this robot is not confined to equipping it with the necessary signals or designing the above receptors—automation is far enough advanced to instal them without particular difficulty. The main difficulty lies in organising a central recoding of the information on the input of the photoelectric cells or magnetic relays, into the quality, strength and consecutiveness of the impulses controlling the servomotors of the steering gear.

The other example has to do with the normal coordination of the movements of man, whose afferent organs function normally but who is faced with an unusual motor task. Attach to the buckle of your belt the upper end of a skiing stick, and fix to the end carrying the ring a weight of 1-2 kg. Next tie two rubber tubes to the opposite sides of the ring. The tubes should be long enough for you to be able to take one tube in your right and the other in your left hand. Place the stick so that the pointed end in front of you rests on a vertical board on which a large

circle, square or other simple geometrical figure is drawn. Now try to trace the figure with the point of the stick, directing it by pulling at the tubes. The stick represents one link of an extremity with two kinematic degrees of freedom, the tubes are analogues of two antagonistic muscles, adding to the system two resilient degrees of freedom. This test (making an excellent showing in an auditorium) convincingly proves to everybody attempting it, how unobedient and difficult to coordinate are only four degrees of freedom, when man disposing of all his receptors is deprived of the motor experience which his bone-muscular motor apparatus begins to accumulate from the first weeks of life.

I believe that the definition of coordination I have given in the above-mentioned works is highly exact and laconic. Coordination of movement is the overcoming of surplus degrees of freedom in the moving organ or, in other words, its transformation into a controlled system. In short, coordination is the organisation of the controllability of the motor apparatus. In the above definition I have deliberately not spoken of fixing, inhibiting, etc., of surplus degrees of freedom, but only of overcoming them, because (as proved by extensive tests with children, sportsmen, and also with hemiparethics and amputated subjects [5], [8], [20], [14]), fixation, which is the most primitive and unprofitable way of eliminating surplus degrees of freedom, is used only at the very beginning, when motor skills are only being acquired, and is later replaced by much more flexible, expedient and economic methods of overcoming this surplus, achieved by the organisation of the whole process. The dominating role played by the organisation of regulatory interactions even in the simple case of control of only two degrees of freedom was obvious in the first example, describing autopilotage along a highway.

It follows from the above definition of coordination that we have to do not with some independent activity, with a purposive act, directed at the external world. It should be regarded rather as a means of ensuring the obedience and flexible executiveness of the motor system; it could be called a sort of servomechanism of the motor system.

The works dealing with the structure of movements explain in detail why a mechanism of motor coordination organised according to the circular principle is a biody-

namical necessity; they also describe some physiological processes of the control interaction, which ensure the coordination control of movement by means of the sensory syntheses of different structural levels. It was shown there that in series of unforeseen and practically uncontrollable forces, requiring continuous perception and overcoming, an important role is assigned not only to external forces but also to reactive forces, inevitably arising during motion in the many-linked kinematic chains of the motor organs, and the complicacy of which is increasing in an enormous progression with every additional link in the articulated chain and with every new degree of freedom of movement. Without going into further particulars about this biodynamic aspect of the problem, let us take up a problem which has not been mentioned in the above works, but which has become extremely acute in view of modern development of physiological thought. If motor coordination is a system of mechanisms, ensuring the controllability of the motor apparatus and enabling the individual to use all its complicated mobility with certainty, what can at present be said about the ways and mechanisms of the control of movement? In what respects can known laws governing this control be useful in applied cybernetics and what aspects or properties of these laws must fall away as specific only to the nervous systems of higher animals and man and are therefore most likely to throw light on the chasm, which still qualitatively divides (and probably will continue for a long time to come) the achievements of automation from the vital activity of highly developed organisms being realised in motor acts.

But before going any further it is essential to bring some clarity into terms and to attempt to make a systematic survey of the block diagrams of self-regulating devices used today (self-regulating control devices will for the sake of brevity be referred to as SD).

All systems of SD, operating according to some parameter, be it a constant or variable one, must contain the following elements:

1) an effector (motor), the work of which is adjusted to the given parameter;

2) programming element, in one way or another introducing the required value of the regulated parameter into the system;

3) receptor, receiving the actual current value of the parameter and signalling about it by some method to the

4) comparator, differentiating between the actual and required value with its magnitude and sign;

5) recoding device, transforming the data of the comparator into corrective impulses feedback into the

6) regulator, controlling the function of the effector according to the given parameter.

The whole system thus comprises a closed interacting circuit—the general diagram is given in Fig. 1 (p. 167). Interconnected between the elements may be ancillary devices—amplifiers, relays, servomotors, etc., having no fundamental importance.

It is convenient to designate the parameters being regulated by short terms used by German authors. Let us therefore call the required value Sw (Sollwert) and the actual value Iw (Istwert): this will make the difference between the two (received by element 4) or the surplus or deficiency (Iw over Sw/Iw-Sw)— Δw.

In the example given by Wiener (19) according to the idea of his companion Arthuro Rosenblueth, the coordinating control in taking a visible object from the table is regarded as a continuous valuation of the decrement in the part of the path the hand still has to pass before it reaches the intended object. The place of the object can be designated as Sw, the current position of the hand as Iw, the constantly decreasing distance between them as the variable Δw (Iw-Sw). I wish to make it clear that here and further, I describe the coordination process in micro-intervals of path and time, basing my method on data my colleagues and I have collected over many years. In this article the variable Sw therefore represents the whole uninterrupted planned path or process of motion by the organ, Iw—the actual current coordinates of the latter. That makes Δw (in the present context) the minimum-threshold deviations, corrected more or less efficiently in the course of movement, an example of which are the deviations of a line drawn by hand with a pencil or the point of a planimeter from the line to be traced. In this sense Δw is not the macrodistance decreasing according to plan but a small magnitude of alternate sign and direction, now arising, now successfully or unsuccessfully inhibited.

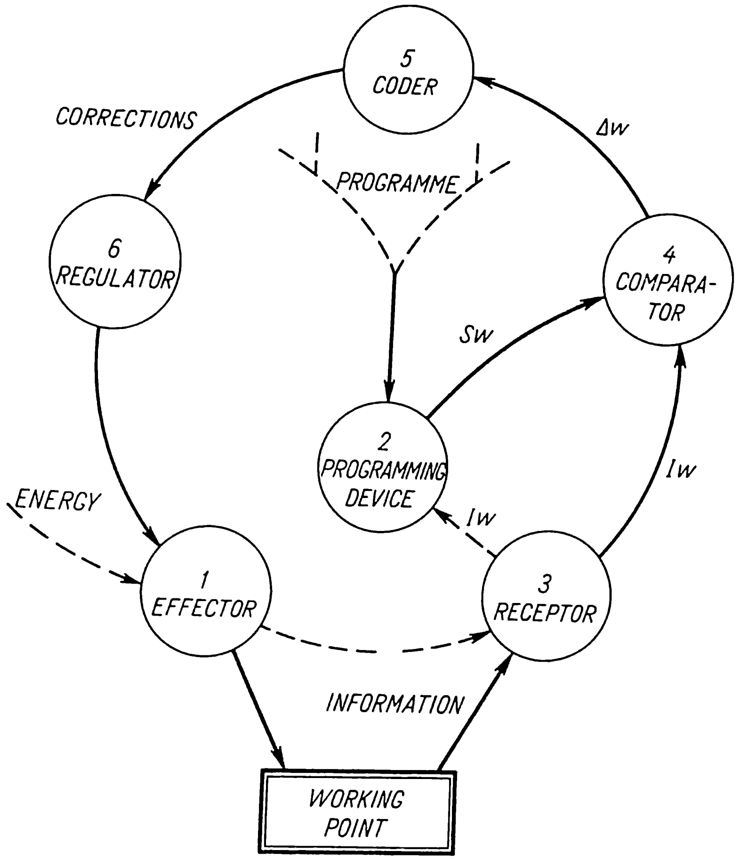

Fig. 1. Simple block diagram of locomotor apparatus

The central command post of the whole circular SD system is programming element 2. According to the nature of the Sw it establishes, all imaginable types of SD are divided into two major classes—SD with a fixed, constant value of Sw (known as stabilising systems) and SD with a variable Sw, changing according to some principle (tracing systems). The law dictating the course according to which the set Sw changes is known as the programme of the SD; the change of the consecutive stages in the realisation of the programme can be sporadic or continuous, and in

some cases may be a function of time, of the path of the business point of the motor-effector, of the intermediate resultant stage, etc. In the most complex and flexible systems even the programmes change and replace each other.

In the present aspect, we are least interested in functionally primitive stabilising systems, though reflex circular control resembling them can be encountered also in physiological objects. Many industrial devices function on this principle, beginning with the centrifugal speed regulator in steam engines. The press-receptor system for the stabilisation of arterial pressure which has been experimentally studied from this vantage point by Wagner (18) may be cited as a biological example. In all its functions and by the very nature of the biodynamics of motor processes the motor apparatus of the organism is organised according to the SD of the tracing type with a continuously programmed change of sequent regulating Sw for every movement.

All the elements of the simplest scheme of circular control contained in our enumeration and in the drawing (see Fig. 1), must in one form or another be present in organic control systems, particularly in the system controlling motion. Our knowledge about the structural elements of the animate motorium is very irregular. We have no knowledge whatsoever about the physiological properties and even about the nervous substrata of elements 5 and 6. Moving elements 1, the motor-effectors of our movements—the skeletal muscles, contrariwise, are objects which have been studied deeply and in detail by physiology and biophysics. The operation of element 3—the set of receptors—has been studied in detail but that study has been one-sided as has been shown in the first part of the article and contains many unclear features in the aspect herein discussed. I shall try to picture here consecutively everything that can be stated positively or can be asserted with a high degree of probability about the physiological aspects of elements 2, 4 and 3, and at the same time shall show the problems we are now approaching but which, as yet, are far from solved. Let us begin with the "commanding post" of the diagram—with programming element 2.

Every voluntary purposeful movement is a reply to a locomotive task determined—directly or indirectly—by a complex situation. The motive act by which the individual

(be it man or an animal) decides to fulfil the task, decides the programme which will be realised with the help of the programming element. What is the real nature of a programme for the control of motion and what controls it in its turn?

In the book on the construction of movements (6) I have dealt in great detail with the origin of sensory corrections and with their retroactive action on movement. In this article we shall have to touch upon an aspect that has found practically no mention in the above book: what do they correct and what directs the course and nature of these corrections.

An observation of the simplest movements belonging to the category of "idle" movements (drawing a line in the air, pointing, etc.) may give the impression that the geometric shape of the movement: the observance of rectilinearity when a straight line has to be drawn, or the observance of direction, when the finger is pointed to a point in space, etc., is the leading principle in the programmed change of Sw, according to which the correction of motion is effected. This would mean to argue from a false premise, since it would accept the particular for the general. In the above types of motion the correction is really made according to the geometric principle, but only because the task is such. In the second example we see that the geometric leading element of the motion is reduced to a point in the field of vision, and if we study cyclographic recordings of the motion, effected with optimal exactness and dexterity, we shall see that an N number of repeated gestures is made by the same subject according to an N number of trajectories failing to coincide and converging only in the immediate vicinity of the point to which the movement is directed. That would mean that the geometric principle of correction is confined to the essential minimum distance of the motion, while in the other parts of the movement different leading principles obtain. That there are such principles in every microelement of the gesture is proved by the certainty and speed with which it takes place (compare it with the gestures of one suffering from motor ataxia) and also by the fact that it faultlessly hits the mark.

The mistake of accepting the particular for the general becomes obvious as soon as we shift our attention from

movements which are geometrical, as far as the sense of the task is concerned, to other types of movements. If we observe comparatively simple purposeful (voluntary) movements, which are continuously repeated, and which therefore lend themselves to automatisation, it will be found that the motor task responsible for them (locomotion, sports, working process, etc.) begins to be resolved satisfactorily much earlier than the movement is automated and stabilised to a considerable geometric standard of repetitions and in many cases already during first attempts. Thus, the kinematic composition of the movement is not the essential invariant, which would determine the success of the act being carried out. If we pass from simple and frequently repeated movements to more complicated ones, often purposeful acts involving chain processes and acts connected with determining external variable conditions and resistances, the broad variability of the kinematic composition becomes a general rule.

Speaking macroscopically about the programme of the movement as a whole, the image or shape of the action's result (final or intermediate) is the only possible factor at which the comprehension of the motor task could be aimed. In what manner, and by what physiological means the image of the action's expected or required final result functions as leading determinant of the kinematic composition of this action and of the programme for the programming element, is a question to which we as yet have no concrete or well-founded answer. But no matter what type of motor activity of a higher organism we analyse, be it elementary actions or chain actions connected with work, writing, articulation, etc., nowhere shall we find any other leading invariant except the sense of the motor task and the anticipation of the required result, which could determine step by step the now fixed, now changing programme of sensory corrections.

The characteristic of the dominant link in the motor act as an understanding of the image or shape of the action's result, which belongs to the field of psychology, and the emphasis that we are as yet unable to name the physiological mechanism on which it is based, does not mean that we deny the existence of the latter or refuse to consider it. In the planning and coordination of movements which form an indissoluble psychophysiological unity, we

are at present able to discover and name the psychological aspect of the leading factor, while physiology, perhaps due to its backwardness in the study of movements (which was mentioned above), has as yet not been able to disclose the physiological aspect of that factor. But ignoramus does not mean ignorabimus and the very name of this article emphasises that its purpose was to pose and draw attention to as yet unsolved problems rather than to answer those already posed.

The 8th chapter of the above-mentioned book (6) gives a detailed account of how and why the kinematic composition of frequently repeated action forms and is stabilised by what is known as the motor habit acquired through exercise. In drawing a short conclusion let us emphasise that even in monotonous and repeated acts the changes in the kinematic pattern and the composition are at first very great, and more or less fixed programmes are not mastered immediately. Exercise to master a new motive act in essence consists of the gradual purposive search for optimal ways of solving the motor task. Thus, a correctly planned exercise repeats time and again not this or that *means* for the solution of the motor task, but the *process* of its solution, and continuously changes and improves the means. It has become obvious to many that "exercise is a sort of repetition without repeating" and that the training in movement which ignores these conditions is no more than mechanical "cramming", a method which has long since been discredited by pedagogical science.*

More concrete information can be given about the *microstructure* of the control of continuous motor processes. Whatever the concrete form assumed by the recodings of the general leading directive of the anticipated solution's image, i.e., its breakdown into detailed elements Sw of direction, speed, power, etc., of every infinitesimal (or minimum-threshold—see below) section of the movement, it is beyond doubt that the lower levels of the programming complex are received exactly as such detailed micro-

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* In gymnastic exercises the kinematic composition (often termed "style") is an integral part of the rational aspect of the task. It therefore requires that the trainer give constant attention to a certain pattern and to the stabilisaion of the kinematic composition in the student, and this in no way contradicts what has been said above about the correct organisation of the exercise.

scopical Sw. It should be mentioned here that the collision of each current proprioception (in the broad or functional sense of the word) with the regular instantaneous directing value of Sw fulfils a minimum of three different functions all of which are equally important for the control. First, the measure of the discrepancy between Iw and Sw (Δw) passing through the circular diagram, determines certain corrective impulses; more will be said about this process when we discuss comparator 4. Second, the reception-information that a definite sequent point has been attained in the realisation of the motor act contains also the impulse that switches the Sw to the next sequent microelement of the programme; this aspect of the process strictly resembles the phenomenon Anokhin (2) has termed "sanctioning afferentation". Finally, this current reception contains a third aspect—apparently one of the phenomena it will be more difficult to reproduce in a model. In every motor act, in which the individual has to overcome changing external forces over which he has no control, the organism continuously collides with irregular and frequently unforeseen complications, which lead the movement astray and make it deviate from the mapped out course. It is impossible or highly inexpedient for the corrective impulses to overcome these complications in order to re-establish the former plane of motion. In these cases the receptor information acts as an inducer for adaptational changes in the programme to be made whilst "in action", from small and purely technical switching of the movement to a new adjacent course and to a full qualitative reorganisation of the programme, changing even the nomenclature of the consecutive elements and stages of the motor act and constituting, in effect, an adoption of a new tactical solution of the task. Such switchings and changes of the programme according to receptor information are much more frequent than would seem at first glance, since in many cases they are effected by the lower coordinating levels, without the assistance of conscious attention (everyone who has at least once in his lifetime walked over uneven ground will fall in with this view).

The book on the construction of movement (6) gives details about the distribution of multiple types and ranks of correcting processes between interacting "background" levels of the coordinating control during the organisation

and mastery of the motion. As was formulated in the book, the phenomenon we call *automatisation* of the motor act is a gradual transmission of numerous technical (background) corrections to the lower coordinating systems, the sensory syntheses of which are most adequate for corrections of this particular kind and quality. The general rule, having virtually no exceptions, on the fading from the field of consciousness of all the component processes of the corrective control, except the ones directly concerned with the leading level of the given movement, was the reason why such level-by-level development of corrections was called automatisation. It should be emphasised here that this many-sided and complex hierarchical system of coordinating levels possessed by higher organisms (and particularly developed in man), one that is able to realise and also to effect instantaneous changes in the most varied programmes of motion by circular control, is probably a consequence of the enormous abundance in the motor apparatus of degrees of freedom (which only so complex a system can make controllable) and it is also the biological reason which enabled organisms possessing so powerful a central apparatus for the control of motion to form (without danger for themselves) during the phylogenesis organs of movement having a countless degree of kinematic and dynamic freedom of action.

Let us now give our attention to element 4 of the diagram (Fig. 1). This element—the comparator—is a most interesting and as yet enigmatic physiological object, but the time is ripe to subject it to a systematic study.

Like in all artificially created SD the circular control must have an element to compare the current values of Iw and Sw and to transmit to the control system's next stage the value of the difference between them (Δw), which is the basis for corrective effector impulses sent to the periphery. If there were no such functional element in the coordination system of the brain, a reception only of the value of Iw, would give no grounds for the switching in of corrections. We have here a unique process in which the comparison and perception of the difference is made *not between two receptions,* simultaneous or successive (as in measurements of the threshold of distinction by some receptor) but between the *current reception* and the *internal guiding element,* which is contained in the central

nervous system in some form (this may be a notion, engramme, etc.—we do not as yet know), one that introduces into the comparison the value of Sw. In this process, too, there are peculiar thresholds "of comparison", which in the simplest cases are obvious and easily measured. Such are, for example, the thresholds for the appearance of the reaction of vestibulo-optic correction in a cyclist when he and his cycle begin to deviate from the vertical; thresholds, which are characterised by the beginning of the correction in the movement of a pencil, when it deviates from an imaginary straight line to be drawn between two points on the paper; thresholds of vocal control, which can be determined by a sound oscillogram when a person learning to sing tries to hold a constant note, etc. The most interesting and specific features of the apparatus under discussion are shown below.

One of the important elements in the control of motor processes is the reception of current variables of the Iw of *speed*. Tachometers of various design in artificial SD all use some physical magnitude which can be directly measured by an apparatus and which is connected with the speed by a simple dependence (friction force, resistance of armature on spring attracted by a magnetic field, etc.). It is important to establish that in our organisms there are no receptor apparatus, able to *perceive speed* directly. But this task is solved in the central nervous system by a very special method and quite obviously with the help of that same comparator or by its nearest homologue. It compares the reception of the current instantaneous position of the moving organ with the *fresh trace* of the reception of the current instantaneous position, held by it Δt time ago. The value Δt can be approximated as lying between 0.07 and 0.12 sec., as I shall try to prove.

If we look into synthetic receptor processes of different kinds, we shall find that the above-mentioned phenomenon of *fresh traces* (as we shall conditionally designate it) is extremely universal and therefore of fundamental importance. If visual perception of movement were not based on a continuous comparison of the current receptions with the fresh traces we could perceive *neither speed nor direction*. Also when we hear a melody or word we perceive not only single consecutive elements—sounds, but also the melody or temporary pattern of the phonemes and their

rate. We feel the qualitative difference in a sequence of tones, going up or going down, distinguish the phoneme "VA" from the phoneme "AV", etc. When my eyes are closed and I feel that a line is drawn with a stick over my skin, I perceive not only and simply the places on which the stick consecutively presses but also the *direction and speed* of its movement on the skin as two different *qualities,* as things primary. Their synthetic, combined primary and the fact that they are a) qualitatively similar to "raw" receptions and b) maintained in active form only during fractions of a second, make the "fresh traces" qualitatively different from ordinary *memory*—the instrument for long-time storage of centrally processed notions.

To control motion there often must be an uninterrupted perception not only of the current values of the difference (Δw) but also of the speed, with which this difference increases or decreases. As has been justly noted by Wagner (18) often, for example, in the case of small but rapidly growing deviations of the Iw, the control receives the greatest benefit exactly from the receptor which marks the changes in the speed of Δw, and is able to sensitively react to the very beginning of a harmful deviation, even before the absolute value of the deviation exceeds the threshold. The irrefutable fact that our sensory syntheses are able to react differently to different speeds at which Δw changes, shows that the phenomenon of "fresh traces" may occur in the comparator, too, and be responsible for the comparison not of Iw with Sw, but of the fresh trace of their difference (Δw) which occurred a fraction of a second ago with the value of this difference at the moment. Speaking mathematically this is a perception of the derivative

$$\frac{d(\Delta w)}{dt}.$$

There is no doubt that the perception of speed and direction, the comparison of Iw and Δw with their "fresh traces" in all qualities of reception, etc., are *not continuous* and take place not according to the differential of time, dt, but according to commensurable short intervals Δt, which we have designated as the "minimum-threshold". They are based on special *temporal* threshold values, apparently in close physiological kinship both with the thresholds, characterising the speed of psychomotor reactions and with

physiological parameters of the groups of lability, refractoriness, constancy of adaptation, etc., and requiring, naturally, immediate study. There can be no doubt that even now psychophysiologists—specialists on the sense organs—will be able to add to and correct what has been said above about the "fresh traces".* I should like to add the following as a working hypothesis.

As far back as the thirties M. N. Livanov found that the amplitudes of the peaks of beta waves on electroencephalograms noticeably change their value from the peaks to the depressions of the alpha waves, that they seem to be modulated by the latter; this could indicate the occurrence of periodic oscillations in the excitation of the cortical elements in the alpha-rhythm. Gray Walter (17) noted that the critical flicker, cinema reproduction, etc., in the optic apparatus very nearly coincides with the frequency of the alpha-rhythm, and even individually changes in parallel with the latter. It is also not accidental that the lower threshold of the frequency being merged by the ear in the specific sensory quality of *sound,* too, lies in that band of frequencies. Further, the approximate observations made by V. S. Gurfinkel (as yet unpublished) of the holding and movement of an empty hand, and also the cyclographic study by L. V. Chkhaidze (10) of the rhythms of acceleration impulses of a cyclist's feet** also show in complete accord that the alternation of the correction impulses present in both cases lie within the alpha wave frequency band, i.e., within 8 to 14 c/s. It would seem correct to assume that this frequency is a manifestation of the rhythmic oscillations in the excitability of all or at least the principal elements of the reflex circuit of SD in our motor apparatus, since these elements undoubtedly must possess mutually

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* Another question that has to be investigated is the connection between the mechanism of "fresh traces" with the psychophysiological mechanism of the whole wide category of engramming and memory. Information gained in the past few years shows that the biologically important category of processes securing the fixation, storage and transmission of information are extremely complicated and many-sided. Further investigations will show to what extent the phenomenon of "fresh traces" differs from other engramming functions that have been studied before, what their anatomic physiological substrata are, etc.

** I wish to express my gratitude to V. S. Gurfinkel and L. V. Chkhaidze for the information they have given me.

synchronised rhythms. In that case we could consider it as the basis of the above-mentioned division of the sensory and coordination processes into minimum-threshold intervals Δt, dividing by intervals of partial refractoriness moments of acute receptivity, which stores the instantaneous impressions of Iw in the form of a "fresh trace" up to the next surge in excitability. The spread of alpha waves in the whole brain cortex, particularly predominant in the receptor zones, and also their synchronisation in all the organs involved, seem to speak in favour of this hypothesis. We should then be able to regard the alpha-rhythm as a mechanism, dictating to the coordination processes their temporary determining parameter—a sort of Sw of time, while the intervals Δt, could be regarded as the counts of an internal physiological pendulum, being to these processes what British physiologists call a pace-maker. It must be emphasised that irrespective of whether this pace-maker is connected with the alpha-rhythm or not, there can be no doubt of its physiological significance as the most important regulatory factor and of the urgent need to subject it to metric study, and also of determining whether or not it is connected with psychophysiological indices, such as the time of simple reaction, personal control, etc.

I shall now deal in brief with one more important aspect of the coordination process, which is closely linked with the phenomena of "fresh traces" and the parameter Δt.

In the processes of motion control we come across situations when great, sometimes decisive importance is attached to corrections of an anticipatory nature, which become especially noticeable when during a certain period of motion corrections of the tracing type become impossible. There is a whole class of such motor acts (known as ballistic movement) which can be effected only with the help of such anticipation—javelin throwing and hitting a mark (throwing of a stone, disc, ball games, etc.), the jumping over a ditch or hurdle, striking an object with swinging hammer, etc. It is impossible not to notice identical anticipatory phenomena also in a number of movements, where these coincide with corrections of the usual tracing type—all sorts of *anticipatory movements*, like those made by a greyhound in pursuit of a beast. The hound is manoeuvring and trying to reach not the position

occupied by the beast at the moment, but anticipates or extrapolates a point traversing the trajectory of the run. The usual grasping of a moving object with the hand, throwing a ball at a fleeing person, placing the racket in a position to strike the ball when playing table-tennis, and many other cases belong to this category. Mittelstaedt (12) proposed to differentiate between the two types of corrections, considering them as two classes of equal importance and to term them respectively Regelung (adjustment) and Steuerung (control). But in the present context other aspects of the problem are more important.

The existence and incidence, much more frequent than would seem at first glance, of anticipatory corrections make us turn our attention to the many-sided importance which anticipation has for the realisation of every purposeful motor act. Even its programming, determined as was shown above by the rational perception of the motor task, is an anticipation of the required result and also of the kinematic means which will be required for its execution (the latter along very general lines). On this "looking into the future" depends an enormous class of psychophysiological processes, known as "set processes", the importance of which has only recently been widely recognised. As in the analysis of the functions of programming element 2, here, too, we have found hierarchic ranks (constructional levels) beginning with the level organising the motor act's programme and to the level, making precise the "micro Sw" from moment to moment or from Δt to Δt. We also cannot bypass the fact that in order to ensure the execution of the microprogramme elements and to carry out and direct the controlled motor process, the set Sw must continuously precede the actual motion, anticipating it by at least minimum-threshold spans equal to Δt, which must be sufficiently large so that the disturbed equilibrium (between the achieved Iw and the Sw drawing it on) ensure the dynamics of the progress to the final result. Thus, speaking semi-figuratively, the current microregulation of the motion is executed all the time between the present moment t and the limits of the interval ranging from $t - \Delta t$ (fresh traces) to $t + \Delta t$ (Sw anticipation).

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In this article I have dealt with a number of problems connected with the control of active manifestations of the vital activity in higher organisms, to the extent suggested by an analysis of motor acts. In another article, dedicated to this same subject, I should consider it expedient to critically consider heuristic models, reproducing expedient motor acts and also problems that have cropped up or are cropping up in this connection, including the functions of the recoding organs, the interdependence between discreet and wave processes in the central nervous system, and, finally, some new lines of applying mathematics to the physiology of processes occurring in the nervous system.

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RESULTS OF EXPERIMENTAL STUDIES ON PROPERTIES OF THE NERVOUS SYSTEM IN MAN

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"PROPERTIES" AND "TYPES"

To Pavlov, with his original typological views, we owe the formulation of two fundamental concepts: the theories of the three basic properties of the nervous system (strength, balance between excitation and inhibition, mobility of nervous processes) and its four principal types.

It must be stressed from the outset that the second of these two concepts by no means follows from the first. Initially, Pavlov built his classification on the principle of balance between the processes of excitation and inhibition; subsequently, he founded it on the strength of the nervous processes, relegating the principle of balance to a secondary position, and only in its latest formulation he consciously resorted to the property known as the mobility of nervous processes which he discovered last. But whatever the principle employed, the number "four" was present in all his classifications. It is not the occasion here to go into the reasons of Pavlov's fidelity to the number four. We must insist, though, that it never followed from his theory of the basic properties. In his latest and most elaborate paper on the subject, Pavlov himself admitted that the number of possible combinations of the basic properties could be extended to at least 24, and yet he did not abandon the concept of four types. It is often thought that the theory of four types originates from Hippocrates (for which Pavlov himself gave cause), and is thus consecrated by antiquity. But, in the first place, Hippocrates never even hinted at a theory of four temperaments, speaking only

about four bodily humors. Secondly, the antiquity of a scientific theory is by no means proof of its validity. Otherwise why not go on supporting the venerable Ptolemaic geocentric system?

Unfortunately, after Pavlov's death the theory of four types began to be viewed as the crux of his typology of the nervous system, overshadowing his truly great discovery of its basic properties. This was particularly detrimental to psychology.

To be able to assess the properties of the nervous system, it was necessary to devise the appropriate methods and obtain proof that each of them applies to a single definite property. This entailed painstaking and complicated research which, moreover, had to be conducted along physiological lines, being concerned with the physiological properties of the nervous system.

It is quite a different matter to single out individuals (children in particular) of the sanguinic, choleric, phlegmatic or melancholic temperamental types. This task is not difficult, whichever way we solve it: by observation, history-taking, or natural and even laboratory experiments. The notions of the four traditional temperaments are rather vague, so that no special demands may be put to the precision and reliability of such determination. When thus approached, the task is limited to characterising certain *psychological* types, which would be unobjectionable if they were not presented as types of nervous activity, i.e., as physiological categories. But the desire of many authors to rest their works on Pavlov's theory and so make them look strictly scientific has the result that purely descriptive psychological characteristics are given pseudophysiological justification, which merely spoils a good deal of otherwise quite satisfactory psychological research.

In our view, the problem discussed cannot be fruitfully developed without resolutely discarding the concept of four types of nervous systems.

SYNDROMES OF BASIC PROPERTIES OF THE NERVOUS SYSTEM

In order to build up a classification of types of nervous activity, it is necessary to determine what properties are to be regarded as basic, what interrelationships exist between them, what possible combinations can the basic

properties form and which combinations are most typical. These questions are today most vital for the development of the theory of types and properties of the nervous system.

In solving these problems, it is natural to follow the concepts of Pavlov. But to follow does not mean simply to repeat. Pavlov's views on the nature of the basic properties altered with the accumulation of new facts. Obviously, the enormous achievements of physiology since 1935-36 cannot but demand substantial readjustments in the understanding of many issues relevant to the nature of the properties and the methods of their assessment.

The properties of the nervous system are manifested in a number of parameters allowing quantitative evaluation by appropriate experimental procedures. The chief methodological means of proving that a certain parameter refers to a definite property is by confronting various experimental findings for every individual under study.

As evident from our findings, the manifestations of each of the basic properties comprise a certain syndrome, i.e., a combination of interconnected and intercorrelated parameters. One or a small group of the latter are basic or referent, having the most direct bearing on a given property or, in other words, serving to assess a determinative aspect of the property in question.

Detailed studies in our laboratory were concerned with one such property, viz., the strength of nervous activity in regard to excitation. This property is characterised by the following parameters, which comprise a sufficiently well-defined syndrome:

1) the ability of the nervous system to endure protracted or frequently repeated excitation without revealing transmarginal inhibition;

2) resistance towards the inhibitory effects of extraneous stimuli;

3) certain features of concentration (or, inversely, irradiation) of the process of excitation;

4) distinctions in the manifestations of the law of force;

5) visual and aural sensitivity, which (see further) are inversely related to the strength of the nervous system, i.e., the weak nervous system shows higher sensory sensitivity than the strong.

The basic or referent parameter in this syndrome is the first, namely, the ability to withstand protracted stimulation without revealing transmarginal inhibition.

Other properties of the nervous system are to be presented in the form of similar syndromes, singling out one of them as basic, i.e., determinative.

As a result of studies in our laboratory involving the comparison of numerous experimental data, we were able to distinguish another syndrome of intercorrelated parameters not correlating with the strength of the nervous system.

In published papers we interpreted this syndrome as a manifestation of the second basic property of the nervous system, i.e., balance between the processes of excitation and inhibition. The syndrome in question incorporated the following parameters:

1) speed of formation of conditioned reflexes and differentiation;

2) comparative amount of "positive" and "inhibitory" errors (i.e., instances of positive response to inhibitory and lack of response to positive stimuli);

3) speed of extinction of unreinforced conditioned reflex;

4) speed of extinction of orienting reflex;

5) value of orienting reflex;

6) features of elaboration of conditioned inhibitor;

7) certain features of the formation of a delayed conditioned reflex, as well as certain aspects of delayed reflexes;

8) features of background EEG (see further).

Our studies gave sufficiently authentic evidence that all these parameters refer to one and the same property independent of the strength of nervous activity. The definition of this second property as the balance of nervous processes is apparently correct, but on profounder considerations, proves to be incomplete and inexhaustive.

Generally, the balance of nervous processes is interpreted as the relationship between the respective *strength* of inhibition and excitation. The strength of the nervous system in regard to excitation (or, as it is often inaccurately called, the strength of excitation) was examined earlier.

The strength of the nervous system in regard to inhibition has yet to be investigated more thoroughly. However, in the first approach, we can define it as the ability of the nervous system to endure a continuous (or extremely

powerful) process of inhibition. The most straightforward way of assessing the strength of the nervous system in regard to inhibition is to test it by protracted differentiation or multiple high frequency repetition of a differentiating stimulus. The balance between the strength of excitation and inhibition is assayed by comparing the results of two standard tests, viz., multiple high-frequency repetition of reinforced conditioned stimuli and similar presentation of differentiating stimuli. The test results give quantitative estimates of both nervous processes in comparable units.

The earlier listed parameters of the property termed as balance of nervous processes are of an entirely different nature. The most noteworthy is the first, namely, the speed of formation of conditioned reflexes and differentiations. There is ample experimental proof that this parameter does not correlate with undoubtable parameters of strength of the nervous system in regard to excitation. Other facts, few thought they be, cause to doubt the existence of correlation between the speed of formation of differentiation and the effects of protracted or multiple presentation of a differentiating stimulus. Hence, when assessing the balance of nervous processes by the mentioned parameters, we draw comparisons not between the strength (in the described meaning) of the processes of excitation and inhibition, but their other aspects.

The above, sufficiently well established, furnishes the grounds for the following hypothesis: along with strength (in the sense of endurance) and mobility (to be dealt with further), nervous processes evince another property, the determinative parameter of which is the facility or speed with which the nervous system generates processes of inhibition and excitation. This property may be defined as the "dynamism" of nervous processes, and is characterised by the described syndrome, the first-named parameter of which, i.e., the speed of formation of conditioned reflexes and differentiations, should be acknowledged as basic or referent (Nebylitsyn, 15).

Thus, according to our hypothesis, the single concept of strength of the nervous system splits into two new concepts, i.e.. two properties should be distinguished instead of one, namely, strength proper (endurance or threshold capacity) and dynamism. Both these properties must be assessed separately in regard to excitation and inhibition.

Accordingly, the property known as balance is to be assessed in regard to strength and dynamism.

As regards Pavlov's "third" property, i.e.. mobility of nervous processes, recent data are decisively against the earlier shared interpretation of the term, which encompassed such diverse parameters as speed of formation and termination of nervous processes, speed of transition from excitation to inhibition and vice versa, speed of a formation and reversal of connections, etc. Obviously, some of these parameters should be relegated to the property which we call dynamism of nervous processes. The term *mobility* must be temporarily retained to denote the property of the nervous system characterised by the speed (facility) of reversal of the signs of various stimuli. This parameter has been thoroughly investigated on animals (but less so on man). In practice, physiologists apply the term *mobility* in this very sense. A number of works, especially the latest by V. V. Krasusky (7), proved the existence of nervous systems which are either balanced or unbalanced in respect of mobility. We must stress, though, that mobility in this sense cannot as yet be described as an integral syndrome of intercorrelated parameters. Hence, we cannot say that the concept of mobility has been elaborated to any appreciable extent.

Researchers in our laboratory revealed yet another property of the nervous system which we call *lability*. This is characterised by the speed of formation and extinction of a given nervous process. The respective parameters do not correlate with those of reversal, i.e., mobility, so that lability is not directly linked with the latter. So far we have investigated the speed of formation and extinction only in regard to the process of excitation. New methods will apparently be found to characterise the speed of development and extinction of inhibition as well.

The corollary to be drawn from the above is that the problem of the structure of the basic properties of the nervous system is far more complex than earlier supposed, but certain progress has been made in its solution.

This progress owes, first, to the introduction of a number of new methods (in the first place, electroencephalography, together with measurement of the skin galvanic reaction and electromyography), and secondly, to the nu-

merical increase of investigations involving comparison of multiple parameters and the use of correlational and factor analysis.

CORRELATION BETWEEN SENSITIVITY AND STRENGTH OF THE NERVOUS SYSTEM

In 1955 B. M. Teplov, one of the authors of this paper, put forward the proposition that weakness of the nervous system is an outcome of its high sensitivity. At that time this was merely a hypothesis founded on the theoretical indications of Pavlov concerning the physiological nature of so-called *threshold capacity*, on analysis of the effects of the then applied methods of raising excitability, and on certain experimental data.

In 1956, though, we obtained the first experimental evidence of the correctness of our proposal (13). A negative correlation was discovered (true, in nine subjects only) between the absolute level of visual sensitivity and the three parameters dealt with in the so-called induction method of appraising the strength of the nervous system (24). After analysis, two out of the three coefficients of correlation proved significant. In a subsequent work (11) the comparison was extended to two analysers—the optical and the acoustic, tests being carried out on a larger number of subjects (37 for the optical and 25 for the acoustic analyser), using several methods of assaying the strength of the nervous system. Comparison between the mean values of absolute sensitivity for groups of subjects with strong and weak nervous systems confirmed the preliminary data. Variations between the mean figures for the optical and acoustic analysers were found to be statistically highly valid.

Among later authors we may note V. I. Rozhdestvenskaya et col. (23) whose object was to compare all methods then employed at our laboratory for assaying the strength and sensitivity of the nervous system in regard to excitation.

Summarising the findings of all researchers who confronted the strength of the nervous system with its absolute sensitivity (33, 16, 15, 30), we see that the mentioned hypothesis has already been experimentally confirmed on

more than 150 subjects, and hence may be considered sufficiently firmly established. Also corroborative are certain data, however scant, obtained in research on animals.

So, M. V. Bobrova revealed direct correlation between the limit dose of caffeine (coefficient of strength) and the motor rheobase in four dogs (1). Still more convincing are the facts discovered in an experiment on 15 dogs by Neumyvaka-Kapustnik and Plaxin (19), who confronted such parameters as the electrical excitability of the neuromuscular apparatus and the strength of the nervous system. The coefficient of correlation in this case reached 0.625 ($p < 0.01$). According to V. K. Kadarik (5) 84 per cent of the dogs in a group of mongrels evinced the strong type of nervous system, and only 16 per cent revealed the weak, whereas the ratio in the group of pure-breds was the reverse, 71 per cent (10 out of 14) belonging to the weak type. It seems logical to agree with the author's explanatory suggestion that selection of dogs with keen smell leads to the prevalence of the weak type of nervous system among pure-breds.

Departing from the cited facts, we formulated the proposition that the ratio between the parameter characterising the strength of the nervous system—the threshold of transmarginal inhibition—and the threshold of sensitivity (absolute threshold of sensation) is a constant value:

$$\frac{R}{r} \approx \text{Const}$$

Although the coefficients of correlation between various factors characterising the strength of the nervous system (each of which may be considered to furnish an approximate estimate of the threshold of transmarginal inhibition) and the absolute thresholds pertaining to the measure of sensitivity, are never too high, the main tendency is retained, namely, a greater absolute threshold usually corresponds to a greater strength of the nervous system. The aforesaid correlation would be even more valid if the experimental findings were not modified by inevitable corrections accounting for the functional condition of the subject, his attitude towards the experiment, the degree of precision of the equipment, etc.

Such a proposition was supported by an experiment demonstrating that, with stimulation intensities expressed in terms of individual thresholds, the more sensitive "weak"

and less sensitive "strong" subjects invariably produce almost coincident response-time curves presenting functions of the intensity of the sound stimulus. The ratio between the upper threshold (the stimulation intensity at which the curve reaches its peak) and the "lower" one (the threshold of acoustic sensitivity) was identical for both groups of subjects, comprising about 4.5 logarithmic units (18).

Thus, a weak nervous system is not at all so "bad", its doubtless advantage being lower sensory thresholds. It is probably this circumstance that should be taken into account when debating the problem of factors enabling subjects with the weak type of nervous system to surmount the difficulties of adaptation.

INVESTIGATION OF THE INHIBITORY PROCESS

The problem of inhibition, considered from the typological standpoint, includes two main issues: (1) assessment of the strength of the nervous system in regard to inhibition and (2) measurement of the speed of formation of inhibitory functional structures (extinguishing, differentiating, delaying and trace-type). The former task is decidedly more difficult, for it is no easy matter to find experimental forms to ensure the required intensity of the inhibitory process in human subjects, providing conditions for assessment of the true endurance of nerve cells in regard to inhibition. That is probably why world literature shows such a dearth of procedures for determining the strength of the human nervous system in regard to inhibition. This problem has not been sufficiently investigated in our laboratory either.

One of the earliest experiments was by V. I. Rozhdestvenskaya (25) who applied the technique of "photochemical" conditioned reflexes, comparing two surmised indices of strength in regard to inhibition, namely, protraction and multiple repetition of the differentiating response. Both parameters produced a satisfactory degree of coincidence. There is good reason to agree with Rozhdestvenskaya when she interprets the disinhibiting effect of the described techniques as the result of extreme over-exertion of the inhibitory process, and consequently of weakness of the nervous system in regard to inhibition.

However, as noted by Teplov (26), the method of photochemical conditioned responses reveals a number of shortcomings limiting the possibilities of its use, especially for practical purposes. Consequently, there is an urgent need to find other parameters of the strength of the nervous system in regard to inhibition, which could be assessed by methods of greater practical convenience. One such technique is the galvanic-skin method, which, however, is not entirely free of disadvantages rather significant from the point of view of practice. Its main fault is that the orienting and disinhibiting effects are displayed in one and the same oscillation of the potential. Therefore, it is hard to say what evokes the galvanic-skin reaction at protracted or multiple presentation of the differentiating stimulus: whether it is actually conditioned by overinhibition or merely by the novelty of the stimulus.

This, apparently, explains the vague results of the attempt undertaken in our laboratory by L. B. Yermolayeva-Tomina (31) to obtain indices of strength in regard to inhibition by use of the galvanic-skin technique (after Tarkhanov). Similar obstacles will probably arise in attempts to apply the vascular, electroencephalographic and suchlike methods for the same purpose. This, on the one hand, should prompt to look for new experimental methods, and on the other, to try a more detailed analysis of accepted parameters from new angles. It is not inconceivable, for example, that spectral analysis of cerebral biocurrents or appraisal of the GSR potential and the contours of a solitary alpha-wave (in EEG) during developing inhibition, might furnish the investigator with adequate and reliable indices of the discussed process in its dynamics, overstrain conditions being included.

Alongside of endurance to inhibition, a no less important characteristic of the individual qualities of a nervous system is its ability to close the circuits of delaying (inhibitory) conditioned responses. As stated earlier, we lay particular stress on the factor underlying this characteristic, denoting it as the "dynamism" of the inhibitory process (the corresponding property concerned with the elaboration of positive connections is defined as *dynamism of excitation*). Individual variations in this parameter appear during the elaboration of extinguishing or differentiating and—in a more complex form—of delaying and

trace-type conditioned responses. These processes may be investigated by a wide range of reflex techniques.

In our laboratory this purpose was served by the photochemical (Maizel [10], Ravich-Shcherbo [20], Rozhdestvenskaya [22]), galvanic-skin (Yermolayeva-Tomina [31]), electromyographic (Kolodnaya [6]), vascular (Rozhdestvenskaya [21]), motor (Leites [9]) and electroencephalographic (Nebylitsyn [15]) methods.

The primary conslusion to be drawn from these researches is concerned with the problem of the "inhibitory" type, i.e., the possibility of inhibition predominating over excitation. As it is known, experiments on dogs show only the reverse (7), i.e., dominant excitation. Experiments on human subjects, however, indicated the possibility of unbalance of the former type (with inhibition predominant), which was manifest, in particular, in the more rapid formation of the differentiating response as compared with positive conditioned reflexes (10, 21, 3), and, under the motor technique, in the predominance of inhibitory errors (missed and delayed responses) over errors of excitation (9). Consequently, we may affirm the existence of cases when either inhibition or excitation are a dominant factor, and it is hard to say which type occurs more often.

Another finding refers to the problem of delayed conditioned responses. Photochemical and electroencephalographic studies gave coincident results indicating that the structure of the properties of the nervous system concerned with the elaboration of delayed responses alters during the very process of their formation. In the initial stage (a conditioned response in the delay interval) there is a marked predominance of excitation, while the final stage of formation is unaccompanied by predominance of either excitation or inhibition, but is apparently governed by some kind of special factor of higher nervous activity (25, 17).

ELECTRICAL ACTIVITY OF THE CEREBRAL CORTEX AND PROPERTIES OF THE NERVOUS SYSTEM

The correlation between EEG indices obtained during repose and various functional tests is of particular interest, since the study of action potentials may provide the key to direct assessment of the intensity, dynamics and topics of the processes of excitation and inhibition. As it is,

though, the results in this field are still very scant, although literature on individual aspects of cerebral bio-electric activity is sufficiently extensive (31, 3). Our first step in this direction was to compare a number of parameters of the electro-encephalogram proper—certain features of its background and various indices relevant to orienting and conditioned orienting alpha-rhythm blockade during the formation (among others) of "sound-light" type responses. These parameters included duration of alpha-rhythm blockade at the first presentation of sound and light stimuli; speed of extinction of the orienting response to sound; dynamics of the formation and extinction of conditioned-orienting alpha-rhythm blockade and dynamics of the formation of differentiating and delayed responses (12, 17). Since each of these parameters could be expressed in precise quantitative terms, it proved possible to compute the numerical coefficients of correlation between all the indices, the obtained matrix of intercorrelations being processed by factor analysis. The results of this sufficiently strict mathematical procedure allowed us to assert that one and the same factor of higher nervous activity underlies all the described parameters of the orienting and conditioned-orienting dynamics of action potentials.

At the time of the experiments, this factor was defined as balance between the processes of excitation and inhibition. Today, however, it can be defined with greater precision, namely, as balance between the processes of excitation and inhibition in respect of dynamism. The higher values of coefficients of correlation between the said parameters (see intercorrelation matrix, Table 1) allow almost any of them to be adopted as a sufficiently reliable index of this property of the nervous system.

Rather interesting correlations are revealed when comparing the indices of "spontaneous" EEG with the parameters of orienting and conditioned alpha-rhythm blockade. The coefficients of rank correlation between the alpha-index, the frequency and the peak amplitude of the alpha-rhythm in repose, on the one hand, and the aforesaid indices on the other, are shown in Table 2. As evident from the table, the alpha-rhythm amplitude has no valid correlations with balance parameters, although the overall "setting" of the connection remains the same (all coefficients have a negative sign). The frequency of the alpha-

Table 1

Intercorrelations Between Parameters of Balance Between Nervous Processes

Parameters	1	2	3	4	5	6	7
1. Duration of alpha-rhythm blockade at first presentation of sound stimulus	—	0.65	0.58	0.48	0.72	0.45	0.48
2. Number of presentations prior to extinction of orienting response to sound	0.65	—	0.50	0.54	0.66	0.76	0.44
3. Duration of alpha-rhythm blockade at first presentation of light stimulus	0.58	0.50	—	0.85	0.69	0.58	0.43
4. Mean duration of alpha-rhythm blockade at 10 first presentations of combined light and sound stimuli	0.48	0.54	0.85	—	0.79	0.63	0.39
5. Mean duration of alpha-rhythm blockade at tests with conditioned stimulus	0.72	0.66	0.69	0.79	—	0.53	0.28
6. Number of presentations of isolated conditioned stimuli prior to extinction of conditioned response	0.45	0.76	0.58	0.63	0.53	—	0.42
7. Number of combined presentations prior to formation of differentiating response	0.48	0.44	0.43	0.38	0.28	0.42	—

Note: Coefficients 0.66 and higher are significant at levels of $p<0.001$; 0.54 and higher — at $p<0.01$; coefficients 0.43 and higher at $p<0.05$; lower values of coefficients are insignificant.

Table 2

Coefficients of Correlation Between EEG Indices of Repose and EEG Parameters of Balance Between Nervous Processes

Indices	Alpha-index	Peak alpha-rhythm amplitude	Alpha-rhythm frequency	Duration of alpha-rhythm blockade at first presentation of sound	Number of presentations before extinction of orienting response to sound	Duration of alpha-rhythm blockade at first presentation of light stimulus	Mean duration of alpha-rhythm blockade at 10 first presentations of light-sound combinations	Mean duration of conditioned alpha-rhythm blockade	Number of presentations before extinction of conditioned response	Number of combinations before formation of differentiating response
Alpha-index		0.60	—0.37	—0.54	—0.64	—0.45	—0.47	—0.61	—0.45	—0.24
Peak alpha-rhythm amplitude	0.60		—0.17	—0.33	—0.31	—0.38	—0.35	—0.31	—0.10	—0.26
Alpha-rhythm frequency	—0.37	—0.17		0.45	0.66	0.39	0.52	0.56	0.32	0.29

rhythm correlates with a number of balance parameters at a statistically acceptable level. Finally, the alpha-index has statistically valid coefficients of correlation with all balance parameters except one—the speed of formation of differentiation.* This indicates that the predominance of excitation as a typological characteristic corresponds, on the whole, to a lower alpha index together with a greater frequency and lower amplitude of the alpha-rhythm. In factorial processing, all three background EEG indices are included in the same factor with the mentioned parameters of balance of nervous processes.

Finally, essential data were obtained by analysis of the possible role of the properties of the nervous system in the assimilation of rhythm by action potentials under the effects of rhythmic light stimulation. This reaction was compared by E. A. Golubeva and L. A. Schwarz with certain parameters of the property which after investigations by M. N. Borisova et col. was tentatively denoted as *lability* of the nervous system (29). It was demonstrated that at high stimulation frequencies (35-80 cps), as well as in summary evaluation for all frequencies, rhythm assimilation correlates with the mentioned parameters at a statistically acceptable level (Golubeva, Schwarz). As regards stimulation frequencies lying in the area of Δ- and Θ- rhythms, their assimilation does not correlate with lability parameters, but, instead, shows a certain dependence on the development of the state of inhibition (4) and the predominance of inhibition as an individual characteristic of the nervous system (Nebylitsyn). Thus, apparently, it may be considered that the reaction of rhythm assimilation is not univalent as regards its correlation with the properties of the nervous system.

It may be surmised, further, that the mechanisms of formation of the aforenamed response at low and higher stimulation frequencies are different. Doubtlessly these highly complicated problems require further thoroughgoing investigation.

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* As regards the alpha-index, similar data were obtained in our laboratory by E. A. Golubeva.

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PART TWO

SENSATIONS PERCEPTIONS

ON THE NATURE OF MENTAL REFLECTION

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For scientific psychology the point of departure in studying the nature and development of the mind is the proposition that the mental is a reflection and that it emerged in the process of development of the organic world as a property of highly organised matter. Any organic body, whether of a simple or complex structure, is characterised by an ability to react in a certain manner to external influences. The ability of organic bodies to respond by certain reactions to influences, i.e., irritability, emerged as a necessary condition for carrying out the main process of life—metabolism. Physiologic regularities distinguish this type of reactions from the simpler physicochemical reactions observed in inanimate nature. Irritability manifests an ability to react independently and in a certain sense actively.

At the lowest stages of development of the animal world, under conditions of a homogeneous environment, adaptational reactions arise in response to external influences of direct biological significance, and it is irritability that reflects these external stimuli.

Complication of the conditions of existence and the presence of such properties of things and phenomena in the surrounding world, which of themselves neither help nor hinder the vital activities of organisms, have rendered the existence of reflection only in this form insufficient. Since the influences, which are of themselves indifferent, are actually stably connected with the vitally important influences there arises an objective necessity to distinguish that which is important for the organism from that which is unimportant and correspondingly to react to the indifferent external influences. A new form of reflecting reality,

which differs from simple irritability, i.e.. mental reflection, arises.

The elaboration of the problems of emergence and development of the mind is connected with the elucidation of the criterion, the main characteristic, which distinguishes the mind from the other forms of reflection.

The point of departure in the solution of this problem is the recognition of the fact that the organism is always bound to the conditions of existence and that the existence of all bonds with the external world is justified by the fact that these bonds serve the purpose of "equilibrating the organism with its environment" (I. P. Pavlov). This is the biological purport of these bonds and their role in the vital activities of the animals.

Pavlov made, as is well known, a fundamental distinction between unconditioned and conditioned reflexes. This naturally gave rise to the question of the relations of the unconditioned and conditioned reflex connections of the organism to the environment and the mental reflection.

There is no single opinion of whether or not an unconditioned reflex is a form of mental reflection of reality.

From the point of view of Pavlovian physiology the criterion of the mental, in other words, the mechanism of emergence of a mental reflection in all its forms is the conditioned reflex. Pavlov stated openly that precisely the conditioned reflex is simultaneously a physiological and mental phenomenon.

In the conditioned reflex it is necessary to see primarily only a fundamental mechanism of the mind precisely because it is a specific mechanism of signalling relations.

A. N. Leontyev's works contain a psychological characterisation of the signalling significance of the mind. He defines sensitivity—the elementary mental phenomenon—as follows: "Sensitivity (ability for sensation) is genetically nothing but irritability with regard to such influences of the environment which correlate the organism with other influences, namely, orient the organism in the environment by performing a signalling function. The necessity for emergence of this form of irritability consists in the fact that it mediates the main vital processes of the organism now operating under more complex environmental conditions (1).

The signalling function of the mental was also noted by other investigators.

The definition of the mental conditioned-reflex mechanism and its signalling function provides the right direction for concrete experimental studies of the question as to the stage of development of the animal world at which this new form of reflection arises. Wherever it is possible to establish emergence of signalling connections with the environment there are reasons to speak of emergence of mental reflection. Precise determination of the rung in the evolutionary ladder on which the ability of the organism to establish signalling connections with the environment arises is a matter of further studies, and the present controversies concerning this question may be settled only experimentally, whereas the fundamental aspect of this question has been very clearly given in Pavlov's theory which offers a key to understanding the mental—both in its emergence in the process of evolution of the organic world and in the process of its further development as the conditions of existence and structure of animal organisms grew more complex.

The question of correlation between the principle of temporariness and conditioned reflex activity, on the one hand, and the question of the nature of the conditioned reflex itself and its correlation with the unconditioned reflex, on the other hand, have a direct bearing on the questions under consideration. Thus in stating the proposition that the principle of temporary connection is a broader concept than its highest expression in the form of a conditioned reflex K. M. Bykov arrives at the conclusion that temporary connections as a general principle of the organism's interaction with the environment are widespread in the animal and even the vegetable world. According to Bykov, only the highest form of temporary connection, which is the conditioned reflex, combines with the mental act of sensation (2). Attaching extensive importance to the concept of temporary connection Bykov severs this principle from the principle of signalling which is indissolubly connected with it. From Bykov's point of view the principle of temporary connection is universal, and all reflexes, including unconditioned reflexes, form according to its laws. On the basis of such a concept of correlation of temporary connections, conditioned and unconditioned

reflexes, it is impossible to indicate a criterion of emergence of mental reflection.

It is well known that conditioned reflexes arise in animals which do not have a cerebral cortex. The coupling function in this case is performed by less complexly organised parts of the central nervous system. If we agree with Bykov that the mechanism of temporary connection has reached the stage of development where its formation began to be accompanied by subjective manifestations only in the higher animals, it is necessary to show the difference between conditioned reflexes possessing the property of having subjective manifestations and conditioned reflexes which do not possess this property. What is in this case the specific physiologic regularity of forming conditioned reflexes which accounts for the emergence of a specific form of reflection? On the basis of what principles is it possible to distinguish in the external influences the stimuli which are reflected in the form of mental phenomena and the stimuli with which the organism enters into temporary relations, but the action of which is not accompanied by emergence of the mental? On the basis of this point of view these questions are difficult to answer.

Of considerable interest for characterisation of the relations of reflex activity to mental reflection is E. A. Asratyan's conception of the conditioned-reflex arc. According to Asratyan "the conditioned-reflex connection is coupled between the nerve cells of the cortical branches of the unconditioned-reflex arc and the arc of the so-called orienting reflex, i.e., between the cortical branches of the arcs of two unconditioned reflexes. A conditioned reflex of the first order is a synthesis of two or more different unconditioned reflexes . . ." (3).

Asratyan proceeds from the fact that the orienting reflex is also but an unconditoned reflex. Other investigators indicate that the orienting reflex resembles both an unconditioned and conditioned reflexes. It may arise in response to non-signalling, as well as to signalling stimuli. The orienting reflex in response to a non-signalling stimulus also possesses certain features of the conditioned reflex. For example, when not reinforced it is inhibited.

The following objection concerning the role of the orienting reflex in the emergence of the conditioned reflex has been made to Asratyan's propositions: if we assume

that the orienting reflex is a component of the conditioned reflex, how should we explain the emergence and strengthening of the conditioned reflex during complete inhibition or considerable weakening of the orienting reflex? The correlation between conditioned and orienting reflexes is apparently more complex.

An interesting attempt at characterising the correlations was made by Y. N. Sokolov. According to Sokolov, both the conditioned stimulus and the response reactions have special, as well as orienting, mechanisms. He suggests that in the elaboration of the temporary connection we should separate the emergence of the orienting reaction from that of the special conditioned reflex. The latter arises in response to special properties of the conditioned stimulus. The role of the orienting reflex is appropriately to tune the analysers for better perception of stimuli and generally to excite the cortex in order to form conditioned reflex connections. Sokolov writes: "If each stimulus is conceived as a complex of specific and non-specific components, the specific components being the agent of the orienting reflex, it is clear that in the formation of the conditioned reflex the action of each stimulus is made up of a special component which stimulates the conditioned reflex and a non-specific component which evokes the orienting reaction" (4). This proposition is of fundamental importance.

The emergence of mental reflection is apparently connected with the characteristics of the stimuli which take upon themselves the performance of the signalling function. The unconditioned-reflex mechanisms of the reactions to external influences play an exceptionally important role in tuning the analysers for better perception of the stimuli. This role is played by the orienting, adaptational and defence unconditioned reflexes. In the case of the defence reflex this influence affects the regulation of the strength and duration of the action of the stimuli on the organism. The general biological function of the defence reflex is to safeguard the organism against destructive, unfavourable action of external stimuli. An active or passive elimination of an unfavourable stimulus or a reduction in the strength of its influence contributes to the best realisation of the organism's temporary connections with the environment. Moreover, the defence reflex may itself be elaborated in a conditioned reflex way. Thus the defence activity of the

organism is organically incorporated into the realisation of conditioned-reflex connections.

In addition to the general tuning of the organism for the best perception of external influences in the form of orienting and defence reflexes various organs possess the ability to regulate the connection of the organism with certain stimuli. This ability manifests itself in formation of adaptational reflexes which help to tune the analysers for a corresponding quality and strength of the stimuli.

In carrying out defensive activity and in the emergence of the adaptational and orienting reflexes it is very important what function the stimulus performs, i.e., whether it plays the role of an unconditioned stimulus or is a signalling conditioned-reflex influence. Thus Sokolov's studies show that signalling stimuli strengthen the orienting reaction. Orientation by means of mental reflection is apparently carried out precisely during establishment of the organism's connections with signalling stimuli, whereas special unconditioned reflex activities connected with excitation of receptors contribute to the best perception of these conditioned-reflex influences.

In appraising the functional significance of the stimulus for the purpose of concluding whether there is any mental reflection in a particular case it should be remembered that this significance cannot be unqualifiedly attached to certain objects and phenomena because, on the one hand, any unconditioned stimulus may under certain conditions become a conditioned stimulus for other activity and, on the other hand, with a change in intensity a signalling stimulus may also evoke unconditioned reflexes (adaptational reflexes, defence reflexes, etc.).

Moreover, for every species of animal there are certain phenomena which more easily than other phenomena cause conditioned-reflex activity. Pavlov called these phenomena natural conditioned stimuli and the reflexes formed in response to them—natural conditioned reflexes. As the experiments conducted by D. A. Biryukov and his associates have shown, a splash of water, a snapping of twigs, and a rustle of leaves are for the duck, beaver and rabbit, respectively, adequate stimuli which more easily than other stimuli cause formation of conditioned reflexes (5). In animals of corresponding species these adequate stimuli form stable orienting reflexes. The vital importance of these stimuli

accounts for the ease with which reflexes are formed in response to them. These influences are of a signalling significance for the organisms, although they often resemble unconditioned-reflex stimuli, while the behaviour resembles conditioned-reflex behaviour. Mental processes are the form of reflection also of these adequate stimuli; the complexity of these mental processes depends both on the character of the external influences themselves and on the rung of the phylogenetic ladder which the particular species of animal occupies.

Hence, the emergence of mental reflection is connected with the activity of the organism carried out in response to the stimuli which assume a signalling significance. The mind as a specific form of reflection appears on the basis of biological reflection in the form of irritability. Special organs emerged in the process of development of animal organisms; these organs acquired an ability to become excited only under the action of peculiar external stimuli—specific irritability of the sense organs made its appearance.

A certain specialisation of irritability evoked by altered conditions of existence arose as a condition and result of the reaction to indifferent external influences. Specific irritability which qualitatively does not differ from irritability in response to biologically important influences gave rise to the signalling function of reflection. The qualitative similarity of the two forms of irritability is attested by the scientifically established fact of emergence of distant sensitivity, which mainly perceives the signalling stimuli from contact sensitivity which serves primarily to effect the constant connections with the vitally important external influences. The specific irritability of the sense organs, which emerged from the general irritability of the entire organism, is the mechanism of perception of signalling stimuli. The signalling role of this irritability, connected with reflection not only of the influence of a stimulus, which is in itself indifferent, but also of its connection with a biologically important influence, distinguishes the new form of reflection from irritability. The very reflection of an indifferent stimulus is possible only inasmuch as it is included in the process of the organism's vital activities through signalling biologically important influences.

Further elaboration of the psychological aspect of the

reflex theory of cerebral activity has become one of the most important problems of psychological science. The theoretical and experimental studies conducted by B. G. Ananyev, Y. I. Boiko, L. M. Wekker, A. N. Leontyev, B. F. Lomov, A. R. Luriya, S. L. Rubinstein, Y. N. Sokolov, A. A. Smirnov, B. M. Teplov and many other psychologists are developing the reflex conception of the mental. At the same time these studies have given rise to theoretical problems which are still awaiting their solution. Since it is impossible to touch in one article upon all problems connected with the development of the psychological aspect of the reflex theory of the mental, we shall dwell mainly on problems of sensuous cognition and the regulatory role of the mind.

The choice of these problems is in large measure dictated by the fact that precisely as a result of their elaboration a considerable part of new experimental data has been received in recent years. Many of the new facts deal with the activity of the analysers, perception of external stimuli and formation of sensory images. In the first place they make it possible to ascertain the conceptions of the mechanisms and nature of sensory reflection.

A new conception of the activity of analysers is being formed. According to this conception the action of a stimulus on an analyser is a complex process involving a series of interacting reflex acts.

The newly-elaborated concept of two ways of conduction of excitation—specific and non-specific—is very essential. The former is connected with transmission of special information (visual, auditory, etc.) to the cortex along pathways specific for each receptor; this information ensures fine discrimination of the properties of objects. The latter runs through the reticular system and serves to transmit tonic, activating influences to the cortex. Unlike the impulses transmitted along a specific way of conduction of excitation, the impulses coming to the reticular system do not transmit special information, but regulate the excitability of cortical cells.

It follows that by participating in the acts of perception an analyser acts as a single whole only in case of interaction of the specific and non-specific systems of excitation.

The conception of the analyser as an afferent-efferent system whose activity clearly exhibits the reflex principle

is also new. The reception of the stimulus is in itself a reflex process in which the receptors also perform the functions of effectors. Efferent fibres running from the centres to the receptors have been discovered in all sense organs. The action of an external stimulus on a receptor leads to inclusion of the central cortical apparatus, and its impulses alter the excitation of the receptors. The data furnished by many modern investigators (Y. G. Shkolnik-Yarros, A. M. Greenstein, Davis, Tasaki, Goldstein, Granit, D. G. Kvasov, Y. N. Sokolov and others) have been added to the facts discovered by R. Kajal and V. M. Bekhterev. The influence of the central nervous system on the receptors is exerted, first, through the effector fibres which form part of sensory nerves, secondly, through the muscular apparatus of the receptors, and, lastly, through the vegetative nervous system.

The reflex regulation of a receptor by the central parts of the nervous system takes place as a function of continuously acting feedback. Feedback acts both in the specific and non-specific ways of conduction of excitation. The activating influence on a receptor of the reticular system leads to a lowering of the threshold of excitation and an increase in lability. The feedback between the reticular system and the cortex maintains a certain level of excitation on which the dynamics of the special information reaching the cortex come into play.

Thus we do not have to oppose the reflex activity of the cortex to the activity of the reticular system. Each of them doing its part, they unite in perceiving and processing the external influences which reach the analysers.

Perception, as reflex activity, is a most complex system of unconditioned and conditioned reflexes specific for each receptor with complex dynamic relations arising within this system. The analysers may be regarded as self-regulating systems which act reflexly and which, by transforming and transmitting signals from the periphery to the centre, so tune themselves as to be able better to select the information coming from the external world. The action of a stimulus on a receptor gives rise to reflex reorganisation of the entire analyser, and the subsequent perception of the stimulus changes in virtue of the change in the activity of the analyser (6).

Systems of analysers, whose natural connections were established in the course of the individual's life and are in certain measure prepared for it phylogenetically, take part in perception.

A suggestion has been made (A. N. Leontyev [7]) that the cerebral mechanisms of the mental faculties and functions historically formed in man are the physiologic organs of the brain—stable reflex structures or systems which perform new functions—forming in the process of ontogenesis. Their formation becomes one of the most important principles of the ontogenesis. They function as a single organ and their functions assume the character of acts which express a special ability, like the ability of analytical perception of spatial relations and logical synthesis. These functional systems form by making conditioned reflex connections, but entering into special functional structures these connections exhibit special dynamics. The system of pitch hearing may serve as an example of such integral systems which underlie the functions that appear as elementary mental faculties.

An attempt to trace the formation of sensory images was made in the experimental studies conducted by B. G. Ananyev, L. M. Wekker, B. F. Lomov, Y. N. Sokolov and others.

The decisive role in forming an integral image of an object is played by the stable interaction of various analysers established in the process of man's cognitive activity through formation of systems of conditioned reflex connections.

The materials of the above studies show that an integral image of an object is a product of a complex system of reflex acts and that only the aggregate of the reflex acts following each other, caused by the action of the object on the receptors and effecting the analysis and synthesis, differentiation and generalisation of the stimuli form a sensation. An image is an aggregate of successively performed reflex acts associated with each other and locking into a single whole with the result that the thing appears to us simultaneously in the multiformity of its aspects and properties.

The construction, for example, of a visual or tactile image may be compared not with fixing an image on a photographic plate, but with construction of an image in a

TV set where the cathode ray, scanning the image, successively sends electric impulses.

Studies of the actual course of reflex activity of the brain show how mental phenomena—sensations, sensory images—arise in the process of this activity. It is mental activity because objects are reflected in its course; it is at the same time nervous activity of a material organ—the brain—governed by all the laws of the dynamics of nervous processes. The external influence cannot be considered only an impetus which starts off the reflex mechanism. A general characteristic of the studies of the work of the analysers comes to the fore; these studies reveal continuous interaction of the analyser and the stimulus, the uninterrupted connection between the mental reflection and the reflected object, the connection which is effected in the systems of multiple reflexes.

Facts attest that the scheme of one reflex arc does not hold both the construction of the object's image and man's objective action. At the same time there arises the question of the correlation of these systems of reflexes in the perceiving part of the reflex process, i.e., construction of sensory images, and further in the executive part of the reflex process—in the regulation of actions.

Attempts to gain an understanding of these systems of reflexes lead to a confusion in their designation: for the correlation of various reflexes concepts of big and small arcs, reflex arcs and circles, and specific reflex acts are used, a new, fourth link is added to the well-known concept of trinomial reflex, imperfect reflexes are mentioned, etc. But the thing is not only that the correlation of systems of reflexes is differently conceived, but also that in connection with this the correlation between the perceiving and executive parts of the reflex process is interpreted differently, and this alters the conception of determination of the mental and determination of man's actions.

If response activity is conceived as an act of behaviour, a more or less complex human action, its connection with the initial influence is a most complex system of numerous interacting and coordinative reflex acts, both conditioned and unconditioned. Reflex activity is directed by the object of reflection which determines the course of the reflex process. The activity of the analysers cannot therefore be reduced to activity according to an internal circle which

couples the periphery and the centre. The concept of the circle may be used to characterise the processes operating in the nervous system during perception of external influences only providing the circular movement of excitation begins with the influence exerted by the object on man and locks on the object, the object sending ever new influences to the receptor. The result of this continuous interaction with the object is the construction of the image which performs the regulatory function with respect to the executive part of the reflex process. The process ends in action directed toward the object, the action changing the relation between the subject and the object.

According to certain opinion, the sensory image, the tactile in particular, must be regarded as an effect of reflex activity of the analyser apparatus. In this case the regulatory role of the image with regard to the executive reflex effects which carry out the action is not denied, but this regulation is reduced to interaction of two reflex effects. The regulatory influence of the image is conceived as a specific case of general principles in interaction of reflex effects similar to the transfer and interference of skills, transfer of motor effects from one motor organ to another. The interaction of the image, as a reflex effect, and the action, as an executive effect, rests, according to the advocates of this view, on the community of the motor components of these effects. Thus a new interpretation of the reflex links is given since the effector link usually implied the movement of the working organ, whereas in this case it is a question of mental phenomena.

The proposition that the image is a reflex effect rests on data that the analyser is a system functioning according to the feedback principle, i.e., a system in which its own reflex arcs lock. Modern studies attest that the receptor is itself an effector, in which case the proposition that the sensory image is a reflex effect of analyser arcs makes the receptor acting as an effector the direct substrate of the image, i.e, ascribes the image to the periphery. With such conception of the image of the object the connection of this image with man's objective activity, his practical activity, is lost. Yet the proposition that the correctness of an object's reflection is tested in the practice of man's actions with this object is of paramount methodological importance. Sechenov's characterisation of an image in-

cluded the muscle sense which reflects the terminal link of the reflex process—man's action with the object. Such an inclusion by Sechenov was possible only because he conceived the formation of the object's image in "series of successive reflexes" and did not consider it possible to isolate the central link of the reflex from its beginning and its end. This thesis is still valid. The view that the image is a reflex effect of the analyser apparatus also ignores the central link—the analytical and synthetic activity of the brain. At the same time the likening of the image interaction, as a reflex effect, to such interaction of the executive effects as the transfer of skills erases the qualitative peculiarity of the regulatory role of the image as a reflection of the objective world.

Like sensation and perception, thinking is effected in the process of reflex activity of the brain. Its specificity consists in the fact that it is a result of interaction of a thinking person not only with directly sensuously perceived reality, but also with the socially elaborated system of knowledge objectivised in the word. The knowledge acquired by an individual is incorporated into his thinking process and continuously functions in him. The entire thinking process is thus socially conditioned. The neurological bases of the thinking process have been less fully disclosed than the physiological regularities of sensory cognition. But what has been revealed attests the reflex character of the activity of the brain which engenders thought.

In addition to the objective character of reflection revealed by the reflex theory, very important for understanding mental phenomena are the characteristics of their regulatory function which they perform in virtue of the fact that they reflect the objective world.

A large group of new facts pertains to afferentation of movements. In the scheme, which was outlined by Sechenov's daring thought aimed into the future, one of the essential propositions was the "principle of coordination of movements with sensation" (10). In connection with this Sechenov specially distinguished the role of muscular sensations as signals of man's own movements and actions, labour actions in particular. Muscular sensations, representing the end of the reflex in the consciousness, reflecting the motor part of the reflex, connect in the series of reflexes the end of one reflex with the beginning of another.

The capital fact of afferentation of movement by sensation was experimentally substantiated by Pavlov who suggested the idea that the construction of a movement, a response reaction of the organism, is effected in the cortex as "the afferent part of the nervous system, as the organ of sensitivity". He noted that the effected movements send impulses to the kinaesthetic cells of the cortex, the stimulation of these cells actively producing these movements (9).

Further elaboration of this idea resulted in the conception of return afferentation which continuously, in the course of movement, comes from the periphery to the centre where the information thus received is analysed. Much more is now known about the role of the perception of reinforcement and the organism's own reactions in the conditioned reflexes. An afferent signal arising as a result of reflex action, sent back to the centre, influences the subsequent course of reflex acts. P. K. Anokhin deems it justified to speak of the existence of a cortical apparatus which performs the function of appraising the results of any reflex act—an acceptor of action forming under the influence of past actions.

The idea of continuous sensory corrections, owing to which movement becomes controlled, underlies the "physiology of the activity" trend (11). The fact that the physiology of movement develops into the physiology of activity signifies the transition from the studies of the biomechanics of the motor apparatus to the problem of the organism's active interaction with the surrounding world. The first question is that of the regulation and central control of the movements effected by means of feedback, of the dynamic relations arising in the motor act and its structural connectedness and integrity. All these questions connecting the physiology of higher nervous activity and psychology with cybernetics have been raised because of the numerous experimental data attesting the corrective role of "sensory syntheses" in the course of the motor act (12).

Movements are defined as purposive acts in which the organism not merely interacts with the environment, but actively influences it in the direction it needs. The movements become controlled and answering the purpose because the sensory apparatus of the motor organs conti-

nuously signal about the course of the motor act, watch it and control it.

In its search of the determinant of the structure of the motor act "physiology of activity" arrives at the fact that the only standard—determinant of the programme of motor activity, of its realisation and correction, according to feedback, may be a motor task formed and in some manner reflected in the brain. It creates an image of that which is not, but which must become, since only an elucidated image of the required future may serve as the basis for putting into shape and programming an action.

Investigation of voluntary motor acts conducted from the standpoint of "physiology of activity" leads to the conclusion that their realisation is connected, first, with the necessity of perceiving the conditions of the action and its appraisal in correlation with the individual himself included in it, which leads to the emergence of a motor task that contains the determination of what is to be done. Secondly, realisation of motor acts is connected with a continuous sensory reflection of the correlation between the action and the object at which this action is aimed.

Like the studies of sensory reflective activity, the studies of motor acts lead to the conclusion that the individual continuously and actively interacts with the object. The regulatory function of the mental is a necessary condition of the adequacy of objective action and the quality of the object at which it is aimed.

The facts at the disposal of the investigators of physiology of movements confirm the correctness of the conception of the essence of the mental as a reflection of reality, and of its role as a regulator of actions, and we consider this the main proposition of the reflex conception of the mental.

The problem of using the psychological concept of image to characterise the leading factor of the motor act and of directing the efforts towards revealing the physiological aspect of this leading factor and examining them in the unity of the processes of programming and coordinating movements coincides with the problem raised by the reflex theory of the mental, which rests on the Leninist theory of reflection, namely, of disclosing the forms of regulation of behaviour by different forms of reflection of reality.

And yet the representatives of "physiology of activity" themselves sharply oppose their trend to the reflex theory. They object to the reflex theory as presumably an "atomistic" theory which fails to consider the integrity of the organism. Arranging the actions accessible to the organism of animals and man in the order of growing complexity they ascribe all reflexes to the end where are the least complex of these actions. Moreover, using the term "reflex" they limit it only to physiology and put a content into it that differs from the content of the Pavlovian concept of the conditioned reflex as a phenomenon at once physiological and mental. The concept of reflex in "physiology of activity" retains the significance which it had in pre-Sechenov's physiology and which is still used by modern West-European physiology.

One of the immediate problems of studying both the physiological and mental aspects of higher nervous activity is to investigate the mechanisms and processes that ensure different levels of regulation of human activity.

One of the problems of psychological research is concretely to link the study of various forms of reflection of the world with man's actions differing as to the level of regulation. For example, such actions of different levels as locomotion, making something in accordance with a certain model, an act of behaviour which not only produces some objective effect, but also has certain social content expressing the relation of a person to other people—all these actions of different levels, including the second-signal speech level, also presuppose different mental processes for their regulation. Afferentation, first of movements, then of actions, and, lastly, of acts of behaviour, incorporates, beginning with the sensory properties of the given object, the whole series of generalisations resulting from human knowledge all the way to socially important ideas which mobilise people in their social activity.

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INTERACTION OF THE SENSE ORGANS*

By S. V. KRAVKOV

The activity of the sense organs is an object of permanent interest for various researchers including physiologists, psychologists and philosophers. V. I. Lenin regarded the physiology of sense organs as one of the corner-stones of the theory of cognition of dialectical materialism. If, however, we survey this broad field of research, we must admit that so far it has chiefly dealt with the structure of various sensory receptors and the changes which the relevant direct stimuli elicit in them. Up to the present, researchers have concentrated on the peripheral anatomo-physiological conditions affecting the qualitative and quantitative characteristics of our sensations. Very little attention was afforded to the central influences on the sense organs which are ever present inasmuch as, in actual reality, man's sensations are inseparably bound with the process of thought, and the body always operates as an integral whole.

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* This article is an abridged translation of a book published under the same title by S. V. Kravkov (1893-1951), a prominent Russian neurophysiologist.

World literature of the last 15 years is poor in systematic works on the subject. The few papers partly confirming and supplementing Kravkov's work with new facts are by J.C.K. Licklider (1959, 1961); Helms und *and.* (1957, 1958); Y. Yamada (1960); P. Grogno et G. Perdriel (1961). The authors rejecting his conclusions are Crawford, Chapanis A., Ronge R. O., Schachter S. (1949) and certain others. Analysis shows, however, that experimental conditions in the latter works considerably varied from those employed by Kravkov et col. (A. I. Bogoslovsky, Y. N. Semyonovskaya et al.).

In the U.S.S.R. the psychophysiological trend in the field was continued, after Kravkov's death, in the laboratory of B. M. Teplov, in the Institute of Psychology of the U.S.S.R. Academy of Pedagogical Sciences.

We must also mention the original school of research on the subject headed in the Soviet Union by Y. N. Sokolov.

The book is not intended as an exhaustive account of central influences and their role in sensory activity, although the author realises that the time is ripe for this problem to be clarified. The book sets itself a more modest task, which is to examine one part of the aforenamed wider problem, namely, the way the condition of one group of sense organs depends on stimuli affecting other sensory systems; the changes apt to follow from such interaction; the psychophysiological laws responsible for the latter; the theoretical conclusions to be drawn from acquaintance with the entire given field from the point of view of the dialectical materialist theory of cognition, and the practical prescriptions to be derived for the betterment of sensory perception.

Considering that changes in the eye are investigated far more thoroughly than in other sense organs and that the author's own research deals with vision, the general problems of interaction between various effective systems will naturally be examined chiefly on examples from the psychophysiology of vision.

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In Soviet science, Academician A. D. Speransky is one of the ardent proponents of the idea of integrity of the human body, mainly from the point of view of the nervous influences acting within it. No interference into the current condition of the nervous system can ever remain a purely local process, but always starts off more or less extensive readjustments of the nervous system at large. Anaesthesia (novocaine blockade) of the lumbar region, for example, proved to affect the course of gastric ulceration, inflammation of the iris and various skin diseases. The logical conclusion is that "stimulation of any point in the complex nervous network can effect changes not only in its adjacent sections, but in distal parts of the body as well". A well-known experiment by Maklakov demonstrated that a mild ultraviolet burn of the back or chest can cause inflammation of the eyes (conjunctivitis), although no ultraviolet radiation may have affected the eyes proper.

In other words, we are faced here with the problem of interaction, interconnection between the sense organs, or,

broadly speaking, interaction between the body's afferent systems.

A special study of this problem may be of interest, we believe, from many angles. In the first place, the evidence of the sense organs is the source of all our knowledge about the surrounding world. "Save through sensations, we can know nothing either of the forms of matter or of the forms of motion"* writes Lenin. In addition, "sensation depends on the brain, nerves, retina, etc., i.e., on matter organised in a definite way".** Investigations on the interaction between sense organs is one of the means of elucidating this relationship. Furthermore, the reactions of our sense organs offer especially convenient material for analysing the general physiological laws operative in the human organism.

That there actually is interaction between the sensory organs is confirmed by any number of everyday observations. A sound like the grating of a knife on glass evokes a sensation of "creeps" in very many people. Light and sounds, especially high-pitched, will aggravate toothache. Extremely high-pitched sounds tend to cause nausea. Pain in one part of the body will often diminish when pain is provoked in another part. For this reason, many people bite their lips, clench their fists, etc., to make the severer pain more bearable. Excessively hot food causes a sensation of high temperature, which annuls the taste. Very heavy objects seem lighter when lifted during aural stimulation by music. Objects which darkness makes indiscernible to one eye become well visible when we open the other eye. Musicians know that good lighting amplifies sound; an orchestra is heard better if the concert hall lights are left on.

Already in the 17th century the well-known Danish anatomist Thomasius Bartolinus described observations according to which people with poor hearing heard better in the light than in darkness. In the late 18th century Ebermaier and Horn made special investigations in which they too found illumination of the head to enhance hearing in people suffering from ear diseases.

A prominent part in research on sensory interaction belongs to Russian scientists, who were largely pioneers

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* V. I. Lenin, *Collected Works*, Vol. 14, p. 302.

** *Ibid.*, p. 55.

in this field of psychophysiology. So, back in 1879 Wedensky observed a case of increased limbic tactile sensitivity under the effect of lighting. Godnev's thesis presented in Kazan (1882) described experiments exhibiting changes in cutaneous, olfactory and auditory sensitivity under varying light conditions.

In the same year 1882, the Russian *Ezhenedelnaya, clinicheskaya gazeta* (*Clinical Weekly*) published Manaseina's *Notes on a Forgotten Case of Dr. Wardrope*. The case in question had to do with paralysis of the left arm and paresis of the left leg, which were cured after one or two months of tactile stimulation by tickling the afflicted palm and heel with a feather.

In 1885 Istamanov investigated the effect of different kinds of stimulation of the sensory nerves on peripheral and cerebral blood volume, blood pressure, pulse frequency and skin temperature. The stimuli employed were tactile (touch, pain, cold and warmth), gustatory, auditory and optical. Some stimuli appeared to cause constriction of the peripheral vessels with concomitant cerebral vasodilatation, while others led to the reverse. Thus, weak tactile sensations, cold, malodorous substances as well as bitter and sour tastes evoked a marked outflow of blood from the limbs with a simultaneous inflow of blood to the cerebral vessels (Fig. 1).

Conversely, sweet tastes, pleasant smells, warmth and mild pain usually caused an increase of limbic volume and cerebral vasostriction. Auditory stimulation, according to Istamanov, is accompanied by a reduction of skin temperature and limbic volume, accelerated pulse and increased

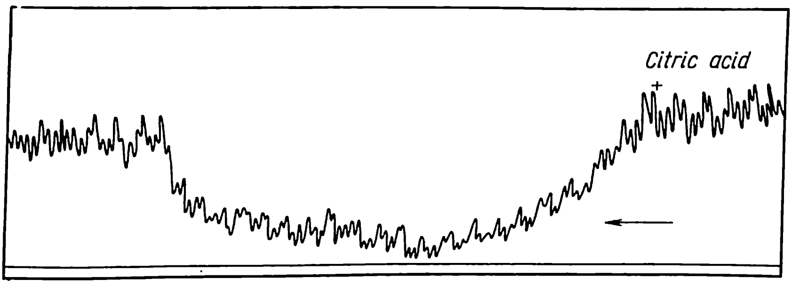

Fig. 1. Vasotonic changes in the hand during gustatory stimulation by citric acid (plethysmogram after Istamanov)

blood pressure. Transition from darkness to light and vice versa reduced the limbic volume, accelerated the pulse and increased the blood pressure.

Shortly before Islamanov, changes in limbic blood supply and respiratory movements under the effect of different sounds were described by Dogil, who also made use of plethysmography. Changes in the blood supply of a hand in one of Dogil's laboratory janitors, a Tatar by nationality, were especially marked when a Tatar melody was played in his presence. This indicates that certain importance in such cases may be attributed to the emotional effect of music.

An extremely interesting observation testifying to the systemic influence of muscular-motor sensations is recorded in one of the later works by I. M. Sechenov, the "father of Russian physiology" on *Effects of Sensory Stimulation on Muscular Activity in Man*. Sechenov employed a special ergograph to investigate the working capacity of his arm and leg and the effects of rest. The results of the experiment were, at first glance, rather unexpected. As Sechenov himself wrote, "most effective in restoring energy, to my surprise, was not the temporary voluntary repose of the working hand but its even shorter relaxation associated with the work of the other hand. To make this more convincing," he says further, "we may recall the effect of music on soldiers tired by a long march or the bracing effect of singing at work".

Interaction between individual organs was a special subject of research by V. Urbantschitsch in the eighties of the last century. This author staged numerous experiments to investigate the effect of aural sensations on colour perception, visual acuity and olfactory, gustatory, and tactile sensitivity as well as changes in other sensations elicited by gustatory, olfactory and tactile stimulation. He recorded numerous observations testifying that such interaction undoubtedly exists. When a vibrating tuning fork is held beside the ear, the colour of a small field observed by the eye often becomes more distinct. However, in some cases of aural stimulation, colour was noticed to disappear. The effects varied with the force and pitch of sounds and variations of colour. Sounds, particularly high-pitched, improved visual acuity. Under the effect of sounds, tastes and smells were perceived better in some cases and worse

in others. Light stimulation usually intensified heard sounds. Alternate shading and lighting of visual fields usually caused notable variations in the intensity of aural sensations. Not infrequently, the pitch of heard sounds was observed to change under varying visual stimulation. Temperature sensations also had their effect on other, particularly colour sensations.

Urbantschitsch himself summarised his experiments as follows. "The absolute physiological law to be derived from all cited observations is that the stimulation of one organ has an influence on other sensations. This influence depends on the sense organ being stimulated, and often proves to vary with the intensity of the primarily elicited sensation. On the other hand, we have observed individual distinctions, whereas, occasionally, repeated experiments on one and the same subject produced different results. I would particularly like to stress that obdurate reactors often had to be trained for some time before they evinced more vivid reactions. Moreover, it should be noted that at different times the intensity of the response in the same individual may vary considerably."

But of course these experiments, however interesting and important for scientific progress, were only a tentative beginning.

In 1904 Academician P. P. Lazarev demonstrated the amplification of sound by light at a meeting of the Physiological Department of the Moscow Association of Natural History, Anthropology and Ethnography. Lazarev alternately illumined and darkened a screen set up before the audience. The spectators could clearly perceive that a sufficiently loud-sounding tuning fork was far better audible in light than in darkness. Rapid alternation of dark and light was accompanied by a vivid sensation of pulsating sound. These experiments were initially described by Lazarev in the magazine *Le physiologie russe,* Vol. 4, and later, in more detail, in the *Izvestia Akademii Nauk* for 1918.

A particular wealth of research on the subject was published, however, in the Soviet Union comparatively recently —during the last 20-30 years. A number of works specially devoted to visual functional changes elicited by various indirect stimuli have been carried out in these years, in particular, by ourselves and our colleagues.

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Changes in absolute scotopic (rod) sensitivity. Numerous experiments by several authors have established scotopic sensitivity to be affected by stimulation of other sense organs. It is also proved with certainty that the rod sensitivity of an eye is definitely related to stimulation of the contralateral organ, as well as of the other afferent system of the same eye, namely, the apparatus of cone vision. Such a relationship should be referred not to interorganic interaction proper, but to the sphere of interactions between afferent systems within a single visual organ. And yet we believe it impossible to omit this question as contributing to a broader approach to the subject of our book.

The experiments of Lebedinsky, Zagorulko and Dionesov, co-workers of Academician Orbeli, demonstrated that illumination of the central retina (the macular region) has the effect of reducing rod sensitivity in the more peripheral retinal regions during the first minutes after its cessation. These observations largely confirmed the hypothesis concerning the existence of mutually antagonistic (reciprocal) relationships between the cone and rod apparatus, which was first put forward in the Soviet Union by Academician Orbeli. The facts established by Lebedinsky, Zagorulko and Dionesov regarding the inhibitory effect of macular stimulation on the peripheral retina, were later fully confirmed by Muzylev and Dobryakova in Kravkov's laboratory. As revealed by Muzylev, this effect is absent in colour-blind subjects whose cone apparatus does not function. Hence, the crucial factor in this case is actually the existence of two afferent systems (cones and rods).

On the other hand, as shown in a number of experiments by Kravkov and Semyonovskaya, brief (1-10 minutes) illumination of the eye with moderately bright light is followed by prolonged marked changes in peripheral sensitivity. These changes are biphasic, viz., during the first minutes sensitivity tends to be lowered, after which it becomes abnormally high, subsequently returning to normal. An obligatory condition of such a sequence is preliminary stimulation of the cone apparatus. Hence, as first demonstrated by Semyonovskaya (1934) and later confirmed by the American authors Rowland and Sloan (1944) and Hecht and Hsia (1845), who, *a propos,* forgot

to mention Semyonovskaya's priority, scotopic sensitivity increases most noticeably under red light, which acts, predominantly, on the cone apparatus (Fig. 2). To date, the last-named circumstances permit us to regard the after-effects of glare as a manifestation of the already mentioned reciprocal relationships between the rod and cone apparatus of the eye. The reduced scotopic sensitivity observed in Orbeli's laboratory after stimulation of the macular area is the result of inhibition irradiating from the cones to the rods. The subsequent hypersensitisation marked by Kravkov

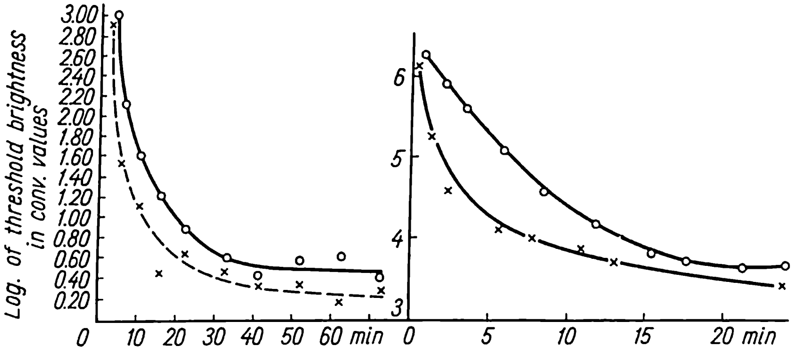


Fig. 2. Comparative scotopic after-effects of stimulation with red and white light of equal brightness.

Curves at left—after Semyonovskaya; right—later data (Rowland and Sloan). Time of dark adaptions in minutes plotted on abscissa; logarithms of threshold brightness—on ordinate. Results of red light illumination denoted by crosses, of white light—by circles

and Semyonovskaya may be regarded as a second phase, as an effect of "facilitation". Inasmuch as the described picture was observed both ipsilaterally and contralaterally, the interaction between the rod and cone apparatus should be acknowledged as central in origin.

Semyonovskaya's experiments also showed that more or less protracted adaptation of one eye to moderately bright light increases the peripheral sensitivity of the other eye (the conjugal pupillary response of the tested eye was eliminated by an artificial pupil).

As regards the effects of sound, Kravkov, Semyonovskaya and Vishnevsky established that stimulation by tones (with frequencies of about 800 and 2,000 cps) or noises of medium

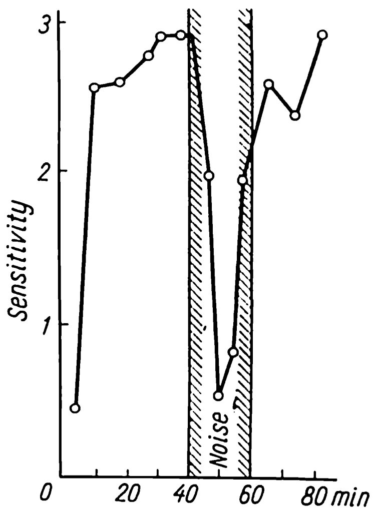


Fig. 3. Reduction of scotopic sensitivity during violent noise (after Kravkov).
Abscissa: time of dark adaptation; Ordinate: scotopic sensitivity. Stimulation by the noise of an aircraft engine (intensity approx. 115 db)

and high intensity was accompanied, as a rule, by a reduction of rod sensitivity to an occasionally considerable extent. For example, as observed by Bogoslovsky and Kravkov, the violent noise of an aircraft engine reduced scotopic sensitivity to 20 per cent of the pre-stimulation level recorded in silence (Fig. 3).

In special experiments, Semyonovskaya further established that, as an after-effect of auditory stimulation, scotopic sensitivity usually proved to be abnormally increased for a sufficiently long time. Similar after-effects were described by Kekcheyev and Ostrovsky even with inaudible high-pitched sounds (approximately 33,000 cps).

The effects of olfactory stimulation on scotopic sensitivity are not sufficiently investigated. According to Makarov, the odours of bergamot oil and pyridine-in-toluene have a sensitising effect. However, the obnoxious emotional effect of the last-named smell was apt to cause a reduction. As observed by Kekcheyev, the odour of ammonium chloride had a sensitising effect.

As regards taste, according to Kekcheyev, experimental stimulation of the tongue with sweet substances raises the peripheral sensitivity of the eye. Our co-worker Galochkina, in as yet unpublished experiments, also observed scotopic sensitisation by the taste of sugar. In this case, however, the increase was negligible.

Urbantschitsch observed scotopic hypersensitisation due to tactile stimuli, such as a stream of air blowing on the skin of the face. He attributed such phenomena to stimulation of the sensory ramuli of *n. trigeminus*, which is

able, in his view, to affect not only visual, but tactile, olfactory and gustatory sensitivity as well.

Experiments by Dionesov, Lebedinsky and Turtsaev, and later Kekcheyev and Matyushenko demonstrated that low temperature stimuli have a notable sensitising effect on peripheral vision. The stimuli employed by Kekcheyev et col. included rubbing of the face with fresh water. According to them, if preliminary threshold values were 15, 12, 28 and 40, the values observed a minute after towelling fell to 2, 2, 9 and 11 respectively. Warmth stimulation of the skin, according to Dobryakova, desensitises peripheral vision.

In the laboratory of Academician Orbeli, Zagorulko, Lebedinsky and Turtsayev staged experiments on the effect of acute pain caused by induction current in the skin of the forearm, during which they measured scotopic sensitivity. In a number of cases the authors observed the latter to change after pain. According to their data, these changes were mostly manifested by a reduction and subsequent increase in sensitivity. As observed by Kharitonov and Anisimova, sharp causalgic pains may be accompanied by acute drops in scotopic sensitivity. After the cessation of pain, the latter considerably improves.

In Kekcheyev's laboratory, Dubinskaya recently investigated the relationship between scotopic sensitivity and muscular-motor stimuli associated with different body postures. Maximum sensitivity occurred in a comfortable sitting posture, falling when the subject stood up. The effects of vestibular stimulation on twilight sensitivity was studied by Belostotsky and Ilyina. The vestibular apparatus was stimulated by rotating the subjects on a Bárány armchair. After five and ten revolutions all of them evinced a considerable reduction of peripheral sensitivity, whose return to normal took from 5 to 30 minutes.

It is interesting to note, finally, that a number of stimuli which act on the body without causing any noticeable sensations may, notwithstanding, have clearly manifest effects on light sensitivity. Thus, ultraviolet irradiation of the skin, as observed in Lazarev's laboratory, tends to desensitise twilight vision. Kekcheyev likewise described changes in peripheral sensitivity under the effects of ultraviolet, X-ray and UHF irradiation of the body. According to experiments by Orlyuk and Davydov, low-dose ultra-

violet irradiation of the skin produced an increase of sensitivity, whereas higher doses reduced it. Reduced sensitivity, according to Kekcheyev, was likewise observed under X-ray irradiation.

Anisimova in Kekcheyev's laboratory found that UHF irradiation (λ = 6-7 cm), of the abdomen and back also exerts an influence on scotopic sensitivity. With repeated irradiation during several days, it was observed to fall from day to day.

More recently, experiments on the visual effects of UHF were staged by Livshits in the laboratory of Academician Orbeli. Livshits employed rather high UHF doses to irradiate the cerebellar area. In a number of experiments drastic (100-150-fold) changes of sensitivity were observed. Livshits associates these findings with Orbeli's theory on the cerebellum as an important regulator of the condition of the sympathetic nervous system.

Recently, Kravkov and Galochkina revealed changes in scotopic sensitivity occasioned by the use of an inadequate stimulus—a weak direct current of about 0.02 and 0.2 mA flowing through the eyeball. During the passage of current, these changes were inverted by altering the pole applied to the eye. With the anode on the eyeball (anelectrotone conditions) and the cathode in the subject's hand, light sensitivity increases; with the cathode on the eyeball (cathelectrotone conditions) it falls. After the current ceases light sensitivity usually exhibits a temporary shift in a direction which is inverse to the changes observed during the flow of current.

Finally, Kekcheyev as well as Dolin described experiments testifying that scotopic sensitivity may alter under the influence of stimuli which, although unable to change it themselves, are associated with other, relevant factors. In other words, the named authors observed changes referable to Pavlov's conditioned reflexes. Kekcheyev and Matyushenko first noted that after scotopic thresholds had been repeatedly lowered by cold-bathing the subject's neck, the same effect could be obtained by simply imitating the movements involved by towelling.

Changes in absolute photopic (cone) sensitivity. Experiments by Vishnevsky and Semyonovskaya demonstrated that medium-level auditory stimuli raise the cone sensitivity of a dark-adapted eye in regard to white light, i.e.,

exert an influence which is the reverse of their effect on scotopic (rod) sensitivity.

However, if we test the foveal (cone) visibility thresholds for various monochromatic rays, the changes caused by sound stimuli prove to vary for different colours (Kravkov). Employing tones of different pitch (about 800 and 2,000 cps) and a wide level-range of noises, Kravkov discovered the sensitivity of a dark-adapted eye to green-blue to increase during auditory stimulation, whereas for orange-red it falls. The terminal spectral areas (extreme red and violet) and the yellow section (approximately 570 mμ) were a case apart: cone sensitivity for those colours was completely unaffected by the acoustic stimuli applied (Fig. 4).

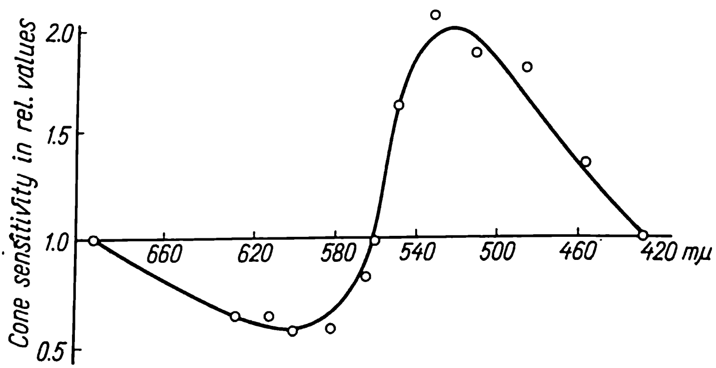


Fig. 4. Changes in dark-adapted cone (colour) sensitivity under auditory stimulation (after Kravkov).
Abscissa: wavelengths of monochromatic light in millimicrons.
Ordinate: relative values of cone sensitivity at tenth minute of sound stimulation (2,100 cps, medium intensity)

The acoustically elicited sensitivity changes may vary depending on the intensity of the sounds (Kravkov). Besides, they show a certain progressive increase when auditory stimulation is continued.

Opposite responses to green and red were recently described by Schwarz, a worker of the Moscow Institute of Psychology. She investigated the effects of postural stimuli (straight and somewhat tilted head positions). In the last-named position, sensitivity to green rays with a wavelength

of about 520 mμ always shows a marked reduction, falling within 90 minutes to as low as 20 per cent of the initial value, whereas sensitivity to orange-red (610 mμ) tends to increase (Fig. 5).

As revealed in experiments by Kravkov and Galochkina, inadequate stimulation in the form of weak electric current flowing through the eye likewise notably affects colour sensitivity. There is an absolutely definite relationship between the nature of the changes and the pole applied to the eye as well as the light wavelength employed to test sensitivity. With the anode on the eye and the cathode in the subject's hand, a dark-adapted sensitivity to green-blue increases during the flow of current, whereas sensitivity to orange-red diminishes. With the cathode on the eye, the picture is reversed, viz., sensitivity to green-blue decreases and sensitivity to orange-red grows. In both cases, with a current intensity up to 0.2 mA and a stimulation time of up to 10 minutes, sensitivity to the terminal and yellow areas of the spectrum remained unchanged (Fig. 6).

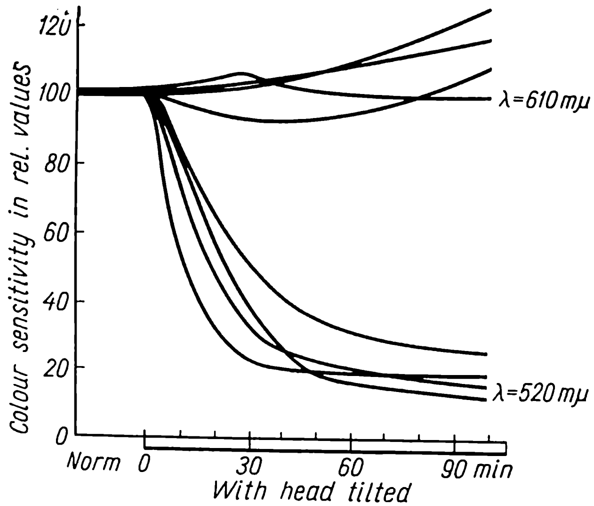


Fig. 5. Changes in colour sensitivity elicited by tilted head posture (after Schwarz).
Abscissa: time of dark adaption during which subjects retained tilted head posture. Ordinate: colour sensitivity in relative values. Findings of experiments on four subjects

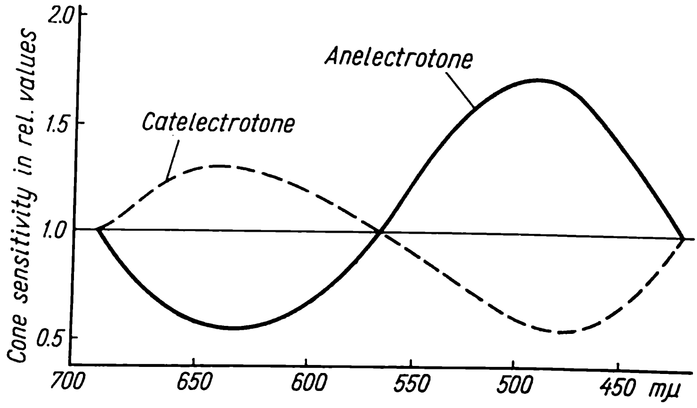


Fig. 6. Electrotonic effects on dark-adapted cone (colour) sensitivity (after Kravkov and Galochkina).
Abscissa: wavelengths of monochromatic light in millimicrons. Ordinate: relative values of cone sensitivity obtained during fourth minute of stimulation with about 20 mA D.C. Continuous curve shows results obtained in anelectrotonic conditions (anode on eyeball); dash curve—under cathelectrotonic conditions (cathode on eyeball)

There is a striking similarity between the picture of changes in anelectrotone conditions (with the anode on the eyeball) and the earlier findings of Kravkov relating to the effect of sound on cone sensitivity.

The fact that colour sensitivity is affected by ultraviolet irradiation of the skin was experimentally established by Puhl who irradiated the body with a quartz lamp for 5 minutes, eliciting an increase of sensitivity to red light. Puhl carried out his experiments with pigment colours.

Discriminatory sensitivity of the eye. As experimentally established by Kravkov, the photopic discriminatory sensitivity of an eye diminishes when the contralateral eye is subjected to light stimulation. This occurs irrespective of conjugal pupillary constriction in the eye under study, an artificial pupil being employed throughout the experiments. Kravkov revealed the following regularity: the brighter the field observed by the tested eye, the lower its discriminatory sensitivity during illumination of the other eye. With constant field brightness, discriminatory sensitivity falls progressively with the increasing brightness of light affect-

ing the other eye, which was established in special investigations by Dzidzishvili.

Kravkov likewise observed that discriminatory sensitivity to white-light brightness contrasts is reduced by simultaneous acoustic stimulation. This process is governed by the same laws as the previously mentioned effect of illumination of the contralateral eye, namely, discriminatory desensitisation proved more significant with brighter fields. A drastic fall was observed in experiments by Kravkov who employed the violent noise of an aircraft engine as a sound stimulus (Fig. 7).

Changes of discriminatory colour sensitivity under various inadequate stimuli were the subject of an old work by the navy physician Parenago who staged his experiments on seamen. They had to discriminate in a spectroscope the minimum wavelength difference discernible at first glance. After a four-hour watch or entire working day discriminatory sensitivity increased in a majority of cases. Inversely, dinner was followed by deterioration. Physical work had varying effects. It is interesting to note that immediately after the noise of gunfire, green-blue discrimination improved, but sensitivity to red remained unchanged or even deteriorated. The last-named facts may be compared with the earlier investigations of Kravkov concerning opposite changes in colour sensitivity to green and red under acoustic stimulation.

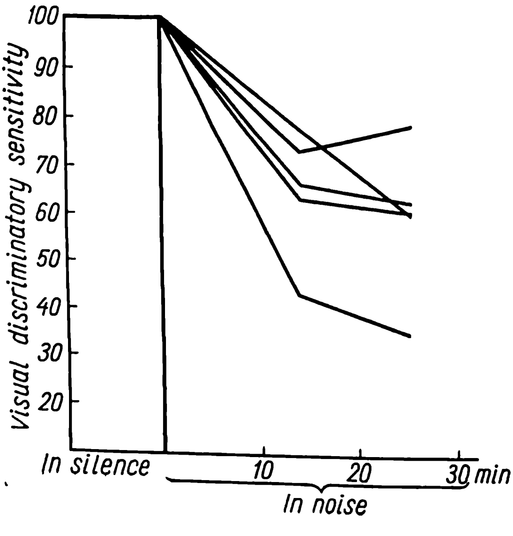


Fig. 7. Reduction of visual discriminatory sensitivity under strong noise stimulation (after Kravkov).
Abscissa: time of dark adaptation in minutes. Ordinate: values of discriminatory sensitivity. Noise stimulus—sound of aircraft engine (intensity approx. 115 db). Findings from five subjects

Critical flicker fusion frequency (c.f.f.) Kravkov observed the c.f.f. for green flicker (520 mμ) to fall during sound stimulation, whereas for orange-red (630 mμ) it grew.

Kravkov carried out an exhaustive study of c.f.f. changes for various monochromatic spectral rays under the influence of olfactory stimuli, viz., the odours of bergamot oil and geraniol. The brightness of flickering light illumining the central retina was so adjusted that with stable dark adaptation the critical flicker frequency was approximately 12-18 cps. The experimental results were quite definite. During olfactory stimulation the c.f.f. for green-blue dropped, whereas for orange-red it rose. After stimulation ceased, the c.f.f. not only returned to the initial level observed before inadequate stimulation, but often changed still further in the same direction, reaching a phase which was the reverse of that observed during stimulation. A similar picture of changes for various monochromatic light rays was obtained by Dobryakova under temperature and gustatory stimulation. The gustatory stimulus applied was sugar, and the temperature stimulus—heat (the hand was heated by air from an electric stove).

It must be stressed that such changes elicited by indirect stimuli acting on other sense organs were observed only at brightnesses corresponding to a critical flicker fusion frequency of 12-18 cps. If we apply a considerably brighter light corresponding to say, 26-30 cps, then, as demonstrated by Kravkov, the same indirect stimuli may alter the critical frequency in a reverse direction. In other words, whereas the critical fusion frequency for weak light is reduced by the given indirect stimulus, for considerably brighter light it may be increased. The explanation of this phenomenon is a subject of discussion elsewhere.

How, then, should we interpret the changes of critical fusion frequency for various monochromatic rays observed by Kravkov and Dobryakova? In what relation do they stand to the changes in colour sensitivity established by the conventional procedure, i.e., by determining the threshold stimulus? Or, speaking more definitely, does the reduction of critical flicker frequency observed under various indirect stimulation always involve a reduction of colour sensitivity? These questions were elucidated in a special investigation by Kravkov. In the course of a single experiment, he measured the changes in critical flicker

frequency and sensitivity thresholds effected by indirect olfactory and gustatory stimuli. His findings showed that when c.f.f. decreased, sensitivity grew and vice versa. The reduction of c.f.f. for green-blue flicker elicited by various indirect stimuli should thus be interpreted as an index of sensitisation to such rays. This relationship between variations of absolute sensitivity and c.f.f. is valid, however, only in the case of comparatively weak flicker corresponding to the above-mentioned c.f.f. of 12-18 cps.

An inverse direction of changes in sensitivity and c.f.f. may be explained if we make the logical allowance that sensitivity variations have a greater influence during the off-phase of flicker, i.e., on the brightness of a fading after-image, than in the on-phases, when the light still acts upon the eye. If this is actually so, a reduction of sensitivity should render the off-phases more noticeable; in other words, a greater frequency of flashes per second should be required to obtain fusion. At present such a point of view is upheld by Bartley, who believes that excitability variations ought to be noticed, primarily, at brightness levels corresponding to the off-phases of flicker stimulation.

Thus, the results of tests on the critical flicker frequency and visibility thresholds for different monochromatic rays may be interrelated. We are justified in stating that acoustic and olfactory stimulation causes dark-adapted sensitivity to green-blue to grow and orange-red sensitivity to fall. Steinhaus and Kelso described a case of increased white-light flicker frequency after cold-bathing of the thigh.

Schiller noted that when critical flicker frequency was already reached, flickering light could be rendered noticeably intermittent by discordant sound combinations and repetitive tactile sensations elicited by rough surfaces. As regards discordant sounds, however, such effects were observed only in sufficiently musical subjects.

Changes of visual acuity. The relationships between visual acuity and various indirect stimuli were the subject of a number of works. The first experiments in the field were staged, as mentioned earlier, by Urbantschitsch. In 1930 Kravkov investigated acuity changes resulting from illumination of the contralateral organ as well as auditory stimulation. In both cases visual acuity improved when the eye under study had to distinguish black objects on a

white background. When the colours were reversed, the mentioned stimuli had an adverse effect.

Finally, Sevryugina demonstrated in our laboratory that an indifferent stimulus, e.g., the weak sound of a metronome, may change visual acuity, provided the stimulus was previously several times combined with conditions invariably affecting this characteristic. This testifies that even such a comparatively complex function as vision may change according to the laws of conditioned reflexes. Initially Sevryugina associated the metronome with intensified illumination. After several such combined presentations, she observed visual acuity to be higher with the metronome than without, even though acuity measurements were made at the same unincreased level of lighting. With a lack of reinforcement, the obtained conditioned response to the metronome gradually disappeared (Fig. 8).

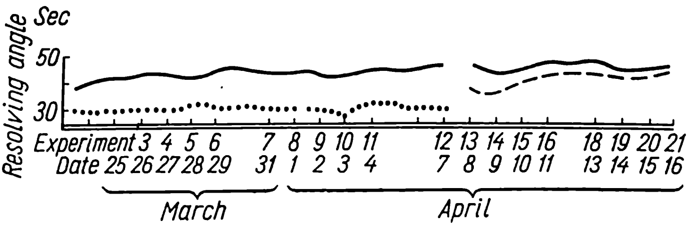


Fig. 8. Conditioned-reflex changes in visual acuity (after Sevryugina).

Abscissa: dates of experiments. Ordinate: angular value of minimum visible gap between squares (″). Continuous line shows results obtained in weak light without metronome; dotted line—in weak light with metronome

Electrical sensitivity of the eye. Experiments in our laboratory showed the electrical sensitivity of the eye to increase during light stimulation of the contralateral eye. Similar effects were obtained by auditory stimulation of a light-adapted eye. The only exception were extremely loud sounds which had a reverse effect, i.e., reduced electrical sensitivity. As observed by Dobryakova, the violent noise of an engine had the same result.

According to Dobryakova, gustatory stimuli likewise change electrical sensitivity. The stimuli included sugar, salt and citric acid. A sweet taste had a sensitising effect,

while acids and salts were desensitisers. Pain had an adverse influence, which was described by Zhuk who observed a reduction of electrical sensitivity in light-adapted eyes during stimulation of the trigeminal nerve effected by tapping sore teeth.

As experimentally established in our laboratory, the electrical sensitivity of the eye may provide a basis for the formation of conditioned reflex connections. A mere word could serve as a conditioned stimulus. Thus, according to Dobryakova, the electrical sensitivity of the eye and tongue increased when the subject was shown a card bearing the words "bright *Sun*" (Fig. 9). In other experi-

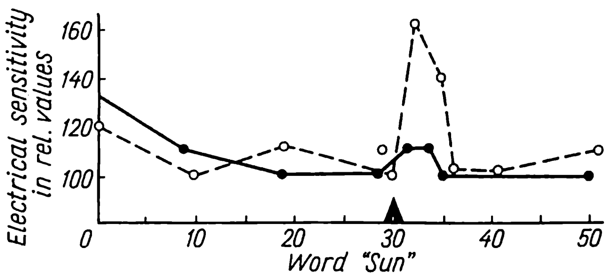


Fig. 9. Conditioned-reflex changes in electrical sensitivity of eye and tongue in response to verbal stimulation (after Dobryakova).
Abscissa: time of dark adaptation in minutes. Ordinate: continuous line—values of electrical sensitivity for eye, dotted line—for tongue. Moment of verbal stimulation shown by arrow on abscissa

ments, electrical sensitivity increased at the experimental stage when the eye was usually subjected to light stimulation, even though no stimulus was presented. In the same experimental series, electrical sensitivity increased at the mere suggestion of a lighted screen being set before the eyes, although the eyes were actually in complete darkness.

An example of the effects of stimuli imperceptible *per se* are the changes in electrical eye sensitivity caused by illumination of the skin on the back, which were investigated in our laboratory by Miller. He irradiated the skin on a subject's back for 20 minutes with a 1,000 w lamp from a distance of 40 cm, absorbing the generated heat by

means of a glass tray with water placed in the path of the light. The result was a noticeable reduction in the electrical sensitivity of the eyes.

Changes of the visual field. In recent experiments Seletskaya revealed changes in the boundaries of the visual field for green and red occasioned by olfactory stimuli (the smell of rosemary and indole). Rosemary caused the boundaries for green to extend, while indole had the reverse effect, i.e., the boundaries narrowed. Occasionally, in similar circumstances, the boundary-changes for red are the reverse, but sometimes do not occur at all. There is literary evidence to the extension of colour visual fields under muscular stress.

After-images. Special experiments were staged by Narikashvili in Academician Orbeli's laboratory to measure the extinction time of Purkinje's after-image, i.e., a positive image of complementary chromaticity. Some of the test series were made in silence, while others were accompanied by sounds of varying frequency (100-1,000 cps) and level (from 10 to 11 decibels). The sounds terminated together with the extinction of the after-image and began within a minute prior to the beginning of light stimulation. In one of the series, the sound was given after the end of light stimulation, i.e., simultaneously with the after-image.

The experiments showed that in some individuals strong acoustic stimulation preceding and accompanying light definitely increases the brightness of the after-image, which in this case completes its development and fades sooner than without the sound.

Stereoscopic vision. According to Semyonovskaya, when a subject looks at objects of low brightness, stereoscopicity may notably increase after preliminary stimulation of the eyes with red light or gustatory stimulation with a sweet substance (glucose tablet).

3

Changes in the perceived loudness of auditory stimuli. We have already mentioned Lazarev's experiments (1904) which demonstrated that sounds may seem considerably louder under illumination of the eyes. He emphasised, however, that "this was true only of strong sounds. With the weakening of the sound to a definite level, the effect

of optical sensations on auditory perception disappears. Below this level, the sound is distorted, i.e., seems weaker when accompanied by light".

In Curzon's experiments the subjects were asked to compare the loudness of two sounds continuing for 0.95 seconds each, with an interval of 0.47 seconds. One of the sounds was accompanied by a flash directed at the central retina and appeared louder. In these experiments, however, the perceived quantitative difference was quite small and can hardly be accepted as valid.

Comparison of two sounds, one of them accompanied or shortly followed by light, was the subject of experiments by Kuroki. Each of the sounds and the interval between them continued one second. The light affected the central retina. According to the author, the indirect light stimulus increased the level of the heard sound. When, however, the entire field of vision was lighted, the effect on loudness was less notable.

Recent publications do not contain sufficiently convincing data on changes in auditory thresholds effected by simultaneous light stimuli. The available work by Child and Wendt cannot be acknowledged to have solved the problem. In the experiments of these authors the subjects determined the audibility of a sound of near-threshold intensity. One of the series was accompanied by light stimulation, while the other was not. The stimulus was a 0.1 second flash with a brightness of about 500 apostils, produced in a circular aperture seen at an angle of two angular degrees. In some cases, the flash was given simultaneously with the beginning of the sound, which continued 0.165 seconds, and in others two, one and 0.5 seconds before and 0.5 seconds after the cessation of the sound.

Perception of the sound was to be signalled by pressing a key. In cases when the light stimulus was presented 0.5 seconds before or simultaneously with the sound, the authors revealed a statistically valid increase of sound perception as compared with cases of sound presentation without the indirect light stimulus. However, the authors themselves think it highly probable that their findings are largely explainable by such factors as the alerting effect of the flash and a degree of autosuggestion aroused by the repeated combined presentation of light and sound. Not to be discounted, finally, is the elusive effect of changes in

muscular tension in the middle ear which may follow in response to the flash. The mentioned experiments, in our view, allow no general conclusions on the effect of specific stimulation of the light receptor on the auditory system for the reason that the light stimulus employed was too short and was limited to the foveal area. Hence, it appears worthwhile to undertake special tests of the influence of more intensive light on the absolute threshold of stimuli of longer duration continuing to act when the transitory body changes linked with the beginning of stimulation have already disappeared.

Experiments of this type were recently carried out by Dobryakova, whose data, in contrast to the earlier findings of Godnev, testify that white illumination of the eyes leads to an increase of auditory sensitivity, whereas darkness diminishes it. It would also be interesting, of course, to see how acoustic sensitivity is specifically affected by the cone apparatus. Of late, Schwarz carried out special experiments to elucidate the effect—if any—of prolonged coloured lighting on acoustic sensitivity. The latter was assayed by the distance at which the subjects could hear the ticking of a pocket watch. The subject was placed in a white cubicle which was illumined by red or green light obtained by use of light filters and equalling approximately 80 luxes at the level of the table where the subject was seated. According to the results of tests on all six subjects, green light tended to raise sensitivity, while red light reduced it (Fig. 10).

As regards the effect of olfactory stimulation on audition, the findings obtained in Propper-Grashchenkov's laboratory testify that the smell of geraniol and benzene reduce the absolute threshold, i.e., increase aural sensitivity. The reduction reached 6-8 decibels.

The relationship between the localisation of heard sounds and simultaneous visual impressions is illustrated by an observation of S. L. Rubinstein, which we shall take the liberty to cite. "At a certain meeting, the speeches were transmitted through several loudspeakers suspended along the right and left walls. At first, sitting rather far and being near-sighted, I could not recognise the speaker. Not noticing how he came to the rostrum, I mistook him for the chairman. But then I heard the speaker's voice (which I knew quite well) coming to me from a near-by loud-

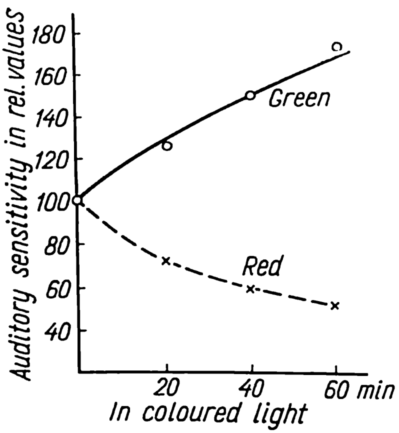


Fig. 10. Changes in auditory sensitivity evoked by coloured light (after Schwarz)

speaker on the left. After a while I saw who it was. or rather, noticed him make several successive movements with the hand coinciding with the accents of his voice. And immediately its sound shifted—now it came to me straight from the front, from the place where the speaker was standing.

"During the recess, I changed my seat for one in the rear on the right, from which I was totally unable to watch the orator, or rather, I could vaguely discern his figure. but could not make out whether he was speaking (the movements of his lips, gestures, etc.); the sound of his voice stopped coming from the rostrum, as was the case before the recess, and again shifted to a loudspeaker, this time on my right. Trying not to disturb my neighbours, I moved forward, nearer to the speaker. At first there was no change in the direction of the sound. But then I looked hard and suddenly noticed the speaker's gestures, i.e., saw in front of me a man making a speech. At that very moment the sound shifted forward towards the rostrum, and I began to hear it from the place where I saw the man himself.

"When the next speaker went forward, I followed him with my eyes, noticing that as soon as he mounted the rostrum the sound of his voice became audible from it. During his speech I began making notes and lost sight of the orator. On finishing my notes, I was surprised to notice that the speaker's voice now came not from the front, where he stood, but from my right, localising in the nearest loudspeaker.

"In all, during that meeting, the sound of speeches shifted about 15 times with invariable regularity. It moved towards the rostrum or back again to the nearest loudspeaker depending on whether I saw the man speaking (moving his lips and hands) or not. In particular, when

the speaker began to gesture and I saw he was speaking, the sound shifted towards him, i.e., I heard him from the rostrum. But when the orator stopped gesturing and I could not see him speak, the sound went back to the loudspeaker. And I must state that I didn't conceive the sound, but perceived or rather sensed it alternately in front or beside me."

4

Sensitivity of the tongue. Taste changes effected by indirect stimuli have likewise not occurred as a special subject in published research. Dobryakova in her thesis describes experiments concerning tongue sensitivity to inadequate stimulation by electric current. With sufficient intensity, the latter causes a salty or bitter sensation in the tongue. According to Dobryakova, illumination of the eyes with white light raises gustatory sensitivity. Noise and the smell of camphor oil reduces the electrical sensitivity of the tongue. Hall and Blakeslee (1945) described a deterioration of adequate taste sensitivity after smoking. There is general literary evidence that gourmets prefer to take meals under bright light. On the other hand, it is known that wine-tasters often close their eyes to get a better idea of a taste.

Doubtlessly, the temperature sensations caused by food may noticeably affect its taste; there must certainly exist an optimum temperature at which the taste of food is discerned best. Stimulation of the taste receptors is usually combined with stimulation of the olfactory receptors. Any food has a more or less noticeable specific smell. It is quite probable, therefore, that in absence of smell, taste sensations would differ from what they are. As far as we know, however, there has been no experimental research on this subject.

The relationship between gustatory and interoceptive stimulation has not been studied either and yet it is common knowledge that appetite in general and specific attitude towards a given food are noticeably affected by the moment's general disposition. Inasmuch as general disposition is largely conditioned by a combination of interoceptive signals, part conscious, part semi-unconscious, we may expect that this type of sensations likewise has its effect on gustatory sensitivity.

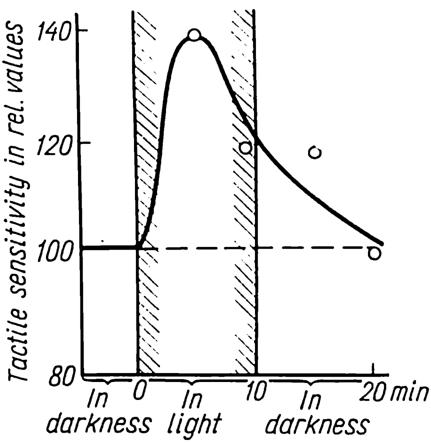


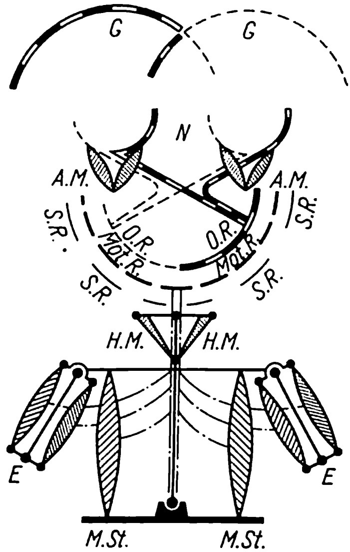
Fig. 11. Changes in manual aesthesiometric sensitivity elicited by light (after Dobryakova)

Tactile and muscular-motor sensitivity. A somewhat larger amount of experimental data are available on the relationships between various kinds of tactile and muscular-motor sensitivity and stimulation of other sensory organs. Earlier we already mentioned that Wedensky and Godnev noted an improvement of tactile sensitivity under illumination as against the level observed in darkness. Their experiments dealt with contact sensitivity and spatial discrimination between two contact points. The improvement of aesthesiometric skin sensitivity during white-light stimulation of the eyes was recently confirmed in experiments by Dobryakova (Fig. 11).

Muscle tonus. Piontkovsky of the Moscow department of the All-Union Institute of Experimental Medicine observed that adequate stimulation of the visual, gustatory, olfactory, auditory and vestibular organs elicits changes in the sensory chronaxia of the manual cutanea. Chronaxia was usually protracted by light, the smell of kerosene, bitter taste and vestibular stimulation.

As observed by Metzger in a series of experiments on more than three hundred subjects, specially adjusted illumination of the eyes evokes definite changes in the tonus of skeletal muscles. Thus, if a subject is asked to stand straight with heels together, and, after a period of darkness, one of his eyes is illumined with diffuse light, there is a tendency to stagger or fall in the direction of the illumined side. The colour of the light is also of significance. Green and red light of equal brilliance have opposite effects. Under red light, subjects requested to stretch their arms forward and keep them parallel will hold them somewhat apart, whereas in green light, the

Fig. 12. Diagram of anatomical connections between retina and skeletal muscles (after Metzger)
G—visual fields; N—retinal fields: O.R.—optical areas of cortex; Mot. R.—motor areas of cortex; S.R.—other sensory regions of cortex; A.M.—eyeball muscles; H.M.—cervical muscles; E—extremities; M. St.—striated muscles of trunk



arms come together. When one eye is lighted with green and the other with red, there is a greater increase of muscular tonus on the side of the eye affected by green light.

Metzger staged separate experimental series to investigate the relationship between the retinal halves and the increase of muscular tonus on a given side of the body. He proved with certainty that with the temporal part of the visual field (i.e., the nasal half of the retina) under white light, the body usually leans towards the light, i.e., towards the temporal side. On the other hand, with the nasal part of the visual field (the temporal half of the retina) under light, the subject's posture deflects in the direction of the nose. The explanation is to be found in the fact that the fibres of *n. opticus* connected with the right retinal halves run to the right hemisphere, and those connected with the left halves—to the left. The motor areas of the right and left hemispheric cortex are connected with the skeletal muscles through a system of fibres, most of which are intercrossed (Fig. 12).

Experiments showed the nasal half of the retina to have a stronger effect on muscular tonus than the temporal half. Hence, with the entire retina of an eye under light, the body leans in the direction of the illumined eye (i.e., in the temporal direction). Monnier and Sigwald revealed that red light illumining the eye increases neuromuscular excitability (shortens chronaxia) chiefly on the side which is opposite to the illumined eye, whereas green light has an inverse effect.

Temperature sensitivity. Under this heading, we may mention a number of works which dealt specifically with changes of temperature sensitivity under the influence of stimuli affecting other sensory organs. Mogenson and English investigated the effect of the colour of viewed objects on their perceived temperature. In a series of experiments they asked subjects to compare the objectively equal temperatures of metal cylinders wrapped in paper of different colours including green, blue, yellow, orange, purple and red. The green and blue cylinders seemed warmer, and the purple one cooler. This result came as a surprise to the authors, who allowed that the subjects had noted not so much the temperature of the cylinders as their pleasing effect on the eyes.

In connection with these experiments Metzger remarked that the visual warmth of the colour and the warmth of the object as felt by the hands have a contrast effect on each other, which biases the perception of temperature. Owing to this, even with objectively equal temperatures, objects of colder colours (blue or green) may seem to feel warmer. This problem cannot be regarded as finally clarified. Inasmuch, however, as the findings of Mogenson and English are sufficiently valid statistically, it must be admitted that the optical sensations produced by the colouring of various objects are not indifferent for tactile discrimination of their temperature.

5

The existence of multiple connections between the sense organs is manifested not only by the multitude of cases when current sensations of one modality are affected by the stimulation of other sense organs. It is also evidenced when a given type of stimulation elicits altogether irrelevant sensations and perceptions related by their quality to other sensory systems. Such a phenomenon, when stimulation elicits secondary sensations and perceptions of different modality, is scientifically known as synaesthesia.

Photisms. One of the first scientific descriptions of photisms was given by Nussbaumer (1873). For many years, he wrote, the effects of air waves which other people perceived only as auditory sensations, caused in him an additional sensation of colour, which was specific for every

kind of sound. As a child, playing with differently sounding toys, he had designated the effect of each sound by its specific "colour". Tones caused various colour sensations in the author; *la* seemed dark-yellow, *mi*—the colour of pigskin at the beginning and deep-blue at the end; *sol*—lemon-yellow at onset and bluish when fading, *do*—whitish. The colour sensations aroused by sounds appeared to exist not outside the author, as objective entities, but somewhere inside him. The same colour sensations would arise from identical sounds several times running. This was specially checked by presenting one and the same sound after considerable intervals.

In some individuals, vowels likewise tend to elicit chromatisms. According to Claparède, the sound *a* is usually perceived as white, *e* as yellow, *i* as red, *oo* as brown. The chromaticity of different vowel sounds may vary from subject to subject, but is highly constant in the same individuals.

Apart from its considerable variability in different individuals, this phenomenon exhibits certain regularities in its manifestations. The higher the sounds, the more light-coloured they usually appear. The vowels *i* and *e* mostly cause light-coloured chromatisms, *a* and *o* are usually associated with medium-light colours, whereas the sounds *yu* and *oo* seem dark. Such coloured hearing was a property of such famous composers as Rimsky-Korsakov and Skryabin. To Skryabin, *C* appeared to have a bright, sunny yellow colouring, while *Fis* seemed deep blue and *F*—red.

Rimsky-Korsakov's chromatisms differed from Skryabin's. There are cases when people chromatise individual words, names and even abstract notions. Suffice it to mention Natasha Rostova in Tolstoy's *War and Peace*, who says about Boris Drubetskoy: "He's ... well, he's light-grey.... Understand?" When her mother expressed bewilderment at such a definition, Natasha exclaimed: "Don't you understand? Nicholas would.... Bezukhov—he's blue, dark-blue and red.... He's nice—dark-blue and red.... Oh, I wish I could explain...."

6

Up to this point we have reviewed a good number of facts doubtlessly confirming the interaction and interconnection of sense organs. These facts, which were established by

special experiments and observations, concern almost all the sensory systems, although obviously, quite a lot is still to be clarified. Nevertheless, analysis and confrontation of the relationships already disclosed allows us to draw certain general conclusions, to outline certain laws of interaction between sense organs. These conclusions refer, primarily, to the routes and means by which such interconnections may be effected.

"Ephaptic" connections. One such route, at first glance the most simple, are changes in the condition of one afferent system elicited by the currently excited conductors of another running in the immediate neighbourhood of conductors belonging to the former. The excitation extant in one set of nerve cells and fibres affects the condition of their adjoining counterparts. This phenomenon may be denoted as contact influence (*per contageonem*). Some authors employ the term "ephaptic route" derived from the Greek word *ephapsis*, meaning contact.

At present we must undoubtedly acknowledge the feasibility of such a mode of influence between two afferent systems. Jasper and Monnier made special studies of the effect of excitation in one fibre on the condition of its neighbour. They took two demyelinised nerve fibres from crustaceans and crossed them, forming the letter T. A certain part of their lengths corresponding to the vertical line of the T was in direct contact. Stimulating the end of one of the fibres, the authors recorded the electrical changes in the other on an oscillograph. As demonstrated by their experiments, the unstimulated fibre evinced changes corresponding to the impulses aroused in the fibre under direct stimulation (Fig. 13).

More recently, the same results were obtained experimentally by Arvanitaki. The author established contact between the demyelinised nerve fibres of the cuttlefish *Sepia officinalis,* one of which he then stimulated, recording the action currents elicited in the other.

Katz and Schmidt established, further, that stimulation of a neighbouring fibre leads to a change in the value of the threshold stimulus and hence in the excitability of the fibre under study. It is beyond our purpose to analyse the nature of the processes by which excitation in one fibre affects the condition of its neighbour. What concerns us most is that by modern findings, such influences are

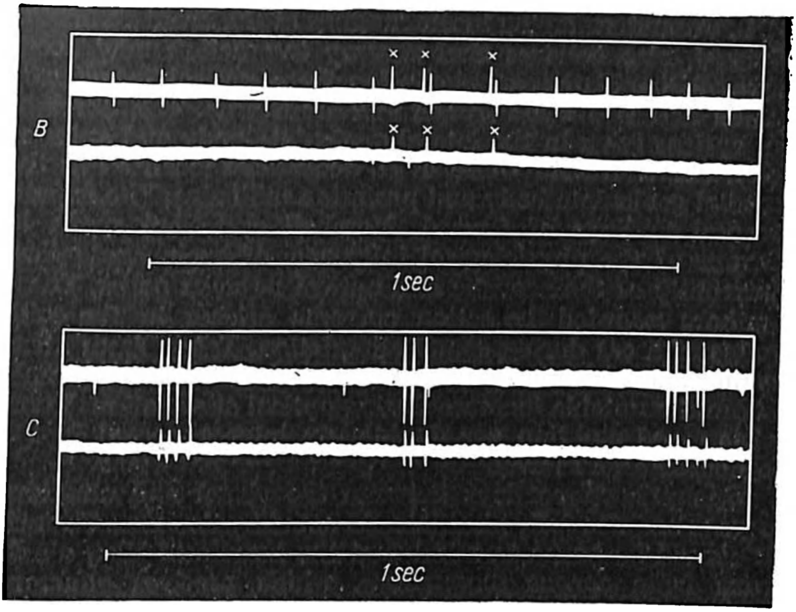


Fig. 13. Ephaptic neural connections (oscillogram after Jasper and Monnier).
Top line in each pair of oscillogram recorded from nerve fibre affected by chemical stimulation; lower line—from unstimulated fibre contacting stimulated nerve. In record *B*, part of the impulses from fibre I (denoted by crosses) elicit impulses in fibre II; in record *C* all impulses elicit responses (time counted from left to right)

actually possible under definite conditions. Such ephaptic connection, i.e., influence through contact, may manifest itself through the development of excitation (appearance of action currents) or changes of excitability (changes of the value of threshold stimuli).

According to Lazarev, ephaptic connections are responsible for the intensification of heard sounds during illumination of the eyes.

In the area of the anterior colliculus and lateral geniculate bodies, the fibres of *n. acousticus* and *n. opticus* are free of myelin insulation and lie quite near each other. Hence, the transfer of excitation from fibre to fibre is highly probable.

L. Freund, referring to the findings of the brain anatomist Spiegel, also believes that sensory interaction may occur through irradiation of excitation from optical to acoustic paths and vice versa in the mid-brain area. The fibres of *n. opticus* lying in the lateral geniculate body and anterior colliculus run near those of *n. acousticus* localised in the medial geniculate body and posterior colliculus. The experimental findings of Gerard, Marshall and Saul speak in favour of the physiological influence of such anatomical proximity of the acoustic and optical nervous paths. These authors recorded the action currents arising in the colliculus of a cat during sound stimulation. Taken from areas connected with the acoustic nerve, these action currents showed a notable increase during optical stimulation. Thus, vision and audition are doubtlessly interconnected in the collicular area as well.

Ephaptic connections between the visual and olfactory organs are also fully plausible. As noted by the same Freund, it should be borne in mind that the bundle of Vicq d'Azir runs from *corpus mammilare,* which receives olfactory impulses, to *nucleus anterior thalami*. On the other side, the *stratum zonale* of the thalamus is entered by the fibres of *n. opticus*. It is in the area of *stratum zonale* and *nucleus anterior,* where olfactory and optical nerve fibres lie near each other, that contact between the olfactory and optical afferent systems may take place.

The intensified irradiation of light-coloured fields under indirect stimulation lies at the root of changes in visual acuity elicited by sound stimulation or illumination of the contralateral eye, which, as mentioned earlier, was also confirmed experimentally. Under such stimulation, the discriminatory acuity for dark objects on light-coloured backgrounds improves, whereas in the reverse case, i.e., with light-coloured objects on a dark background, it deteriorates. Understandably, the intensification of positive irradiation in the former case will make the gaps between discriminated objects more discernible, while in the latter, inversely, such gaps will be annulled owing to the illusory expansion of light-coloured objects. These facts concerning the relationship between vision and indirect sensory stimulation may be interpreted as a sequel of hyperexcitation of the visual apparatus due to the proximity of the optical and acoustic neural tracts, i.e., to ephaptic connections.

Recent works have established more specific relationships in this type of connections, so far mostly in regard to vision. Thus, experiments by Kravkov on the relationship between visual irradiation and auditory stimulation revealed that the latter's influence depends on the degree of brightness contrast between the background and the object whose irradiation is being investigated. Thus, with one and the same sound stimulus, the irradiation of a white object on a black background increases, i.e., the object seems to expand still more, whereas the irradiation of a dark-grey object on a black background diminishes, i.e., such an object begins to seem smaller. These facts are illustrated in Fig. 14, where the values characterising

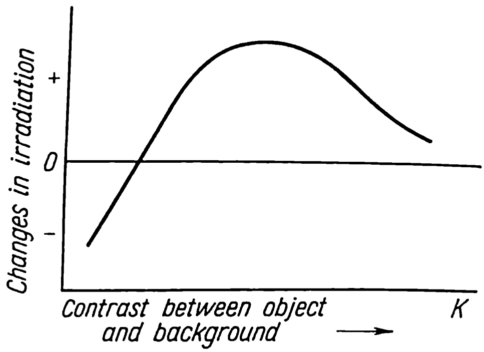


Fig. 14. Acoustically evoked changes in light irradiation conditional upon value of contrast between object and background (after Kravkov)

the changes of irradiation under the influence of sound stimuli are plotted on the ordinate and those showing the brightness contrast between the object and the background—on the abscissa (contrast increases from left to right).

Principle of levelling and accentuation. In order to explain the cited findings,* one has to admit that the added excitation of the visual apparatus evoked by sound is not evenly distributed over the entire visual field, but concentrates in the sections which are already more excited, rather less affecting the weakly excited areas. This is accompanied by an increase of interfield contrast, provided

* For details, see S. V. Kravkov "Certain Regularities in Relationships Between Vision and Indirect Stimulation". *Problems of Physiological Optics.* Vol. 4, 1947.

the excitation difference between the fields was already sufficiently high. Inversely, if the latter was negligible, the effects of indirect sound stimuli tend to level off the contrast. Thus, the additional excitation arising in the process of mutual interaction between various sense organs is governed by a principle which is defined as the law of levelling and accentuation. This principle provides an explanation of many facts. Thus, Lazarev noted that light stimulation intensified heard sounds only if the latter were sufficiently loud, whereas weak sounds remained unaffected. Accordingly, the value of added excitation is a function of the excitation caused by direct stimuli.

We may mention, finally, the opposite effects of one and the same indirect stimulus (flicker of high and low brilliance) on c.f.f., described by Kravkov. Bright flicker tends to increase the c.f.f., whereas weak flicker decreases it. With bright flicker, the added excitation concentrates on fields of highly contrasting brightness, increasing the contrast still further, thereby eliciting an increase of the c.f.f. With weaker flicker, inversely, the excitation added by the indirect stimulus is distributed more or less evenly between both phases (on- and off-, i.e., flash and extinction), accordingly reducing the c.f.f.

The fact that the added excitation provided by stimulation of one sense organ chiefly concentrates in the most excited section of a second stimulated organ, relates the described regularities to the principle of dominance formulated in physiology by A. A. Ukhtomsky, according to whom "the dominant excitation focus accumulates in itself the excitation originating in remote sources".*

Intercentral connections. The existence of functional connections between the cortical centres associated with various sensory organs is also testified by electrophysiological findings. Livanov, for example, recorded the action potentials of the cortical auditory areas in a rabbit, establishing that they tend to change when the animal's eyes are stimulated by intermittent flicker. In such cases, according to Livanov, the potential oscillations originating in the auditory cortex begin to display rhythms corresponding to the light stimulus (Fig. 15).

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* A. A. Ukhtomsky, *The Principle of Dominance. New Contributions to the Reflexology and Physiology of the Nervous System*. Moscow-Leningrad, 1925, p. 60.

The connections between different nerve centres may be either conjugate or antagonistic. There are numerous facts which testify to the existence of antagonistic, i.e., reciprocal relationships between certain sensory modalities. These include, primarily, pain and coarse temperature sensitivity on the one hand and tactile and proprioceptive sensitivity on the other. Head in his well-known experiments observed changes of skin sensitivity after severing one of the sensory nerves in his own hand. During gradual

Fig. 15. Effect of light stimulation on cerebrogram of rabbit's auditory cortex (after Livanov).
Vertical dashes at top denote moments of stimulation

recovery from the operation Head noted that at the initial stage fine tactile sensitivity was totally absent in the skin area innervated by the severed nerve, but temperature and pain sensations arose as before. The latter, however, were of somewhat unusual nature, always extremely intense and hard to localise, i.e., diffuse. But with the recovery of fine tactile sensitivity, the pain and temperature sensations lost their hyperpathetic and diffuse character. There was reason to suppose that fine tactile sensitivity had an inhibitory effect on the reactions of nerves responsible for pain and temperature sensations.

The existence of such antagonistic connections between nerve centres concerned with tactile and proprioceptive sensitivity, on the one hand, and pain sensations, on the other, is testified by the more recent experiments of Orbeli and Pankratov.

Definite functional connections of an intercentral order should be acknowledged to exist between the efferent systems of central (cone) and peripheral (rod) vision. Initially, by analogy with the described facts referring to the spheres of tactile and pain sensitivity, Academician Orbeli surmised the possibility of antagonism, i.e., reciprocity, between the apparatus of rod and cone vision. Later experiments fully confirmed such a proposition. The earlier

described experiments of Lebedinsky, Kravkov, Semyonovskaya and others, demonstrated that illumination of the central retina has the immediate effect of reducing peripheral, i.e., rod vision, and vice versa. The same effect is evident during illumination of the central retina in one eye while peripheral sensitivity is measured in the other. Here, consequently, we also have an instance of interaction between centres.

As already mentioned, in experiments on a colour-blind subject, i.e., a person with a disabled cone apparatus, Muzylev failed to notice irradiation of inhibitory effects from the fovea to the periphery. The phenomenon concerned therefore actually presented a picture of interaction between the cone and rod apparatus.

In a recent work, Kravkov and Semyonovskaya revealed peripheral vision to be subject to the influence of both green- and red-sensitive cones. True, the temporal characteristics of the development of these inhibitory effects apparently depend on the colour of the stimulus affecting the cones. Intercentral neural connections may also be held responsible in cases when optical stimulation affects the skeletal muscular tonus.

The role of the autonomic nervous system. The autonomic system is a major route of interaction between various sensory organs. According to modern concepts, largely substantiated by the work of the laboratory of Academician Orbeli, the autonomic system acts as a major regulator of the functional properties and vital physicochemical conditions of various parts of the body, including the sense organs. This adaptive and trophic activity is effected completely "beyond our will" thanks to widely ramified systems of neural connections.

According to modern anatomophysiological data, the centripetal impulses arriving from all human sense organs invariably enter the thalamic and hypothalamic areas of the diencephalon. Here, too, are the neural structures acting as autonomic centres and governing major bodily reactions such as changes of blood pressure, respiration, water, carbohydrate, lipoid and protein metabolism, etc. It is not surprising, therefore, that stimulation of any given receptor, apart from its specific effect, i.e., sensations, may give rise to more or less widespread autonomic changes in the body. These changes may naturally affect the condition and

activity of all other sense organs, although not directly affected by any stimuli. Such autonomic reactions arising in response to a given sensory stimulation are well known from everyday observations. Olfactory stimuli may affect respiration; obnoxious odours cause nausea and vomitory movements. Sounds may often accelerate the heart-beat and increase the muscular tonus. Pain stimulation occasionally evokes profuse perspiration. Light falling on the eyes causes reflex contraction of the pupils, etc.

There are histological data testifying to the presence in our sense organs of fine centrifugal fibres related to the sympathetic division of the autonomic system. In the olfactory nervous apparatus such fibres were discovered by Academician Orbeli and Yuryeva. "Bearing in mind", wrote Academician Orbeli, "that most, perhaps even all receptors have double innervation, which is firmly established histologically, I presumed that the secondary or accessory innervation of the sense organs is not centripetal, but centrifugal, probably of sympathetic origin, and, perhaps, performs an adaptive and trophic role in regard to the receptors."

Propper-Grashchenkov and his colleagues established the existence of direct sympathetic innervation of the skin receptors.

The sense organs are so closely bound with the autonomic system that, according to certain neurologists, the traditional relegation of the receptors to the somatic system is sufficiently arbitrary. "Each of the receptors may produce a response on the part of both the somatic and visceral (autonomic—*S.K.*) apparatus," writes, for example, Prof. Greenstein. Through the hypothalamic area, sensory stimulations may be transmitted to the pituitary. The latter, as we know, is an endocrine gland secreting a number of hormones affecting growth, sex-gland development, adrenocortical activity, carbohydrate and lipoid metabolism, etc. The intermediary pituitary secretes a special hormone known as intermedin, which, according to some authors, (Jores), has an influence on the retina, reducing the retinal pigment to its dark-adapted state and accelerating dark-adaption of the eye. Of late, considerable scientific attention has been devoted specifically to the relationship between light stimulation of the eyes and pituitary activity. Anatomically, according to Frey, Scharrer et al. connection

between the retina and pituitary may be effected through the so-called basal optical root and the optical and hypothalamic roots passing through the tuber cinereum.

Kohler and Rodewald observed that light stimulation of the eyes causes the pituitary to secrete melanophorin, a hormone which changes the colouring of certain fishes and frogs. The same authors demonstrated that the short-wave part of the spectrum has most potent effects on the pituitary. Considerably earlier Puchet established that the plaice can adapt itself to the colour of the soil only when its eyes and the sympathetic innervation of chromatophores are intact. According to Benois, illumination of the eyes markedly stimulated puberty in birds.

Thus, the cited anatomophysiological data leave no doubt that the activity of the sense organs is most intimately associated with the condition of the autonomic system. Changes in the latter are always more or less diffuse, involving substantial body sections, if not the whole organism. Hence, understandably, the autonomic system may and does actually present one of the major pathways through which one sense organ influences another.

Let us examine a few concrete instances of interaction between sense organs to be accounted for by such influence. First of all, we should like to dwell on a number of facts concerning colour vision changes elicited by stimulation of other sense organs. A research series carried out in Kravkov's laboratory established that colour sensitivity undergoes absolutely homogeneous changes from such apparently different indirect stimuli as tones, noises, the smells of bergamot oil and geraniol, sweet tastes, etc. Namely, green-blue sensitivity increases, while orange-red sensitivity diminishes.

Naturally, such identity between the effects of indirect stimuli on colour vision prompted us to look for a common factor responsible for the changes evoked in the body. Considering that all the stimuli quickened the subjects' pulse, we suggested the aforesaid common factor to be excitation of the sympathetic division of the autonomic system. This surmise became all the more feasible after we tested the effect of conjunctivally introduced adrenalin on colour sensitivity. Adrenalin, as we know, is an agent predominantly stimulating the sympathetic nervous system. Its effects proved to elicit exactly the same changes in

colour sensitivity as are observed with the above-mentioned indirect stimuli, i.e., sensitivity to green-blue rays increased, whereas sensitivity to orange-red diminished.

The experiments staged by Seletskaya in the Psychology Sector of the Institute of Philosophy of the U.S.S.R. Academy of Sciences, demonstrated that the administration of ephedrine, a sympathomimetic, usually raises visual sensitivity to green and reduces it to red. On the other hand, carbocholine, a parasympathicomimetic, mostly had directly opposite effects.

Experiments by Kravkov and Galochkina established that the picture of hypersensitisation to green and hyposensitivity to red is obtained when weak direct current of the ascending type (i.e., with the anode on the eyeball) is passed through a dark-adapted eye. As we know, the relative concentration of calcium ions in electrolytes tends to grow near the anode. As known from physiology (e.g., the works of Zondek), an increased concentration of calcium ions often acts the same as excitation of a sympathetic nerve. Thus, our surmise about the autonomic substratum of the mentioned changes in colour sensitivity is confirmed in this respect as well. Hence, it may be acknowledged that auditory stimulation, as well as the smells of bergamot oil and geraniol and sweet tastes, have an excitatory effect on the sympathetic division of the autonomic system. The colour-sensitive systems of the eye are of various autonomic nature, whence some of them benefit and others lose from the increase of sympathetic tone.

From the standpoint of the trichromatic theory of Young-Helmholtz, the green- and blue-sensitive apparatus should be sympathicotropic, as opposed to the red-sensitive system which, conversely, is inhibited by sympathetic excitation. In very many instances the parasympathetic system acts as an antagonist of the sympathetic division of the autonomic system. Pilocarpine is the principal agent stimulating the parasympathetic system. When Kravkov and Yakovleva introduced it into a subject's dark-adapted eye, colour sensitivity actually changed in a manner exactly opposite to the changes effected by adrenalin, i.e., green-blue sensitivity diminished, while orange-red sensitivity grew. Having examined a variety of colour-sensitive structures, we may conclude that different afferent systems may be oppositely affected by hyperactivity of either

department of the autonomic system. Hence, they will evince opposite changes in response to individual stimuli relevant to the autonomic system. This statement may be illustrated by the experimental findings of Schwarz on the effect of a tilted head posture on visual (and acoustic) sensitivity.

As mentioned earlier, Schwarz found that with a tilted head visual sensitivity to green (as well as acoustic sensitivity) decreased notably, while red sensitivity tended to increase. In the view of neurologists, a tilted head posture creates conditions which favour the predominant excitation of the parasympathetic system (vagus). In other experiments Schwarz and Kravkov discovered that during intensive respiration (hyperventilation) green sensitivity drops, whereas sensitivity to red grows, i.e., once again these sensory devices react oppositely to identical agencies. The experimentally revealed different autonomic nature of the green- and red-sensitive apparatus is in satisfactory agreement with findings on the opposite effects of red and green light on certain physiological functions. Thus, Zaretskaya's experiments established that intraocular pressure changes in opposite directions when the contralateral eye is exposed to green and red light, i.e., falls in the former case and grows in the latter. As we know, intraocular pressure is governed by a number of factors undoubtedly linked with the autonomic system.

It will be pertinent to recall an old finding by the Moscow otiatrist Stein, who personally observed and demonstrated at a meeting of the Ear Clinic of the Moscow University a marked ophthalmoscopically visible vasostriction in the human retina developing during auditory stimulation by a tuning fork with a frequency of approximately 2,048 cps. If, like a number of authors (Duke-Elder), we contend that similar effects may be evoked by stimulation of the sympathetic nervous system, then Stein's experiment offers extra proof to the sympathicotropicity of aural stimulation. As another confirmation of the same, we may recall an old work by Parinaud in which aural stimuli caused the migration of retinal pigments. On the other hand, as observed more recently by Kuvatov and Robinson on frogs and by Arkhangelsky, Holz and Rayeva on dogs, the retinal pigment epithelium may migrate during stimulation of the cervical sympathetic nerve.

Autonomic shifts are probably responsible for the earlier mentioned scotopic changes during vestibular stimulation (Belostotsky and Ilyina). Vestibular stimulation (rotation on Bárány's chair) apparently excited the parasympathetic system, which affected rod sensitivity. Scotopic vision also deteriorated when a subject tilted his head backwards (as in experiments by Schwarz), which likewise may be attributed to parasympathetic hyperexcitation. This is confirmed by other symptoms often observed with a tilted head (e.g., nausea). The scotopic sensitivity, according to Kravkov and Galochkina, is affected by weak direct current flowing through the eye. According to modern views (Zondek) the current-elicited variations in ion-concentration are similar to the changes evoked in a given organ by stimulation of one of the parts of the autonomic system. As observed by Kekcheyev, various autonomic tests (Aschner's, Lug's, Abrahams', etc.), besides eliciting pulse changes, invariably cause scotopic variations.

We may likewise recall the recent experiments by Livshits in Orbeli's laboratory, which demonstrated that UHF stimulation of the cerebellum may considerably change the level of scotopic sensitivity. These results are also interpreted as evidence of the linkage between the visual apparatus and the sympathetic system, inasmuch as, according to Orbeli, the cerebellum is a major regulator of this system.

The autonomic changes elicited by a given sensory stimulus are usually diffuse, i.e., systemic. This should serve to explain the facts revealed in our laboratory by Dobryakova. In her experiments optical stimulation was followed by changes in the electrical sensitivity not only of the eye, but also of the tongue, which itself had not been subject to any stimulation. On the other hand, the same author observed that stimulation of the tongue during several minutes with a solution of common salt produced a reduction of electrical sensitivity in both the tongue and the eye. The systemic effect of stimuli acting on the autonomic system is well seen from the old experiments by Godnev, Manaseina and Islamanov. According to Godnev, optical stimulation raised olfactory, gustatory and tactile sensitivity simultaneously. In Manaseina's experiments, mild tactile stimulation (tickling the skin near the mouth, eyes and ears) caused notable vasomotor changes through-

out the body. Istamanov likewise found that tactile, gustatory, auditory and visual stimuli alter the conditions of cerebral and limbic blood supply as well as the pulse.

Sensory conditioned reflexes. Along with numerous unconditioned stimuli capable of exerting influence on the activity of a given sense organ, there is an infinite multitude of possible (potential) indirect conditioned stimuli endowed with the same ability.

Conditioned sensory responses have been elicited by the sound of a metronome or tuning fork, and by keeping the eyes in darkness for a certain length of time.

Subsequently, Dobryakova observed adequate visual, ophthalmoelectrical and aural sensitisation when a subject was merely placed in a room where he had previously undergone experiments, i.e., was affected by certain visual stimuli which cannot of themselves cause such changes. Being repeatedly combined with a state of alertness, which in this case acts as an unconditioned stimulus,* the very sight of the experimental room began to exert the same influence on the sense organs. In a well-known experimental series by Sevryugina, conditioned-reflex connections were brought into play when the sound of a metronome caused a marked response in such a complex function as visual acuity. In this regard, we must also mention the findings of Pshonik in Bykov's laboratory, who described changes in temperature sensations arising as a conditioned response to aural stimulation.

At present it is beyond all doubt that conditioned sensory connections may be elaborated between any afferent systems of the body. Inasmuch as any sense organ is subject to the effects of definite conditioned stimuli, any agency taken at random may be brought into conditioned or temporal connection with the said stimuli. The resultant conditioned sensory reflexes are governed, largely, by the same laws as the secretory reflexes investigated by Pavlov's school. They may be generalised or differentiated; with a lack of reinforcement they cease, fade, etc.

As observed in our laboratory, conditioned sensory reflexes in man form much faster than salivary reflexes in dogs. As few as 5-6 combinations of the indifferent and

* The influence of alertness on eye sensitivity was shown in special experiments by Y. N. Semyonovskaya (*Problems of Physiological Optics*, Vol. IV, 1947).

unconditioned agents are sufficient. As first demonstrated by Dobryakova in our laboratory, sensory conditioned reflexes may be formed with the help of the second signal system, i.e., in response to a word denoting a conditioned stimulus. The subjective "set" of experimental subjects—their expectation of the unconditioned stimulus, is also a factor in the development of conditioned-reflex sensory changes.

It is obvious, therefore, that the formation of sensory conditioned connections opens infinite opportunities for mutual influence between sense organs.

7

In every particular case, the interaction of two sense organs depends on a multitude of conditions, some of which we shall examine.

Strength of indirect (collateral) stimulus. To begin with, the reaction of any given afferent system to stimulation affecting another sensory system largely depends on the intensity of the acting stimulus. The strength of an indirect stimulus is of major importance. By changing it, we are often able to obtain effects of diametrically opposite polarity. If a weak indirect stimulus increases the excitability of a given sensory organ, intensification of the same stimulus may induce a positive effect to become negative, whereby the sensitivity of the reacting organ is reduced. Examples of such dependence between the effect and intensity of indirect stimulation are numerous.

Teplov, Galochkina and other authors investigated the effect of light stimulation of one point of the retina on the sensitivity of another lying at a certain distance from the former. The experiments showed that weaker stimulation sensitised the reacting retinal points, while stimuli of medium intensity left it unchanged, further intensification of the inductor leading to a reduction of sensitivity, i.e., the effect of the indirect stimulus underwent inversion (Fig. 16).

Experiments in our laboratory dealt with the effect of sound stimuli on the electrical sensitivity of the eye. Weak sounds were found to increase the electrical sensitivity of a light-adapted eye, while sufficiently loud sounds reduced it. A similar relationship in regard to the effect of

muscular-motor stress on peripheral visual sensitivity was described by Kekcheyev: easy muscular work increased scotopic sensitivity, while heavy work caused its reduction.

We may also mention an experimental series carried out by Kravkov to investigate the effect of sounds of vary-

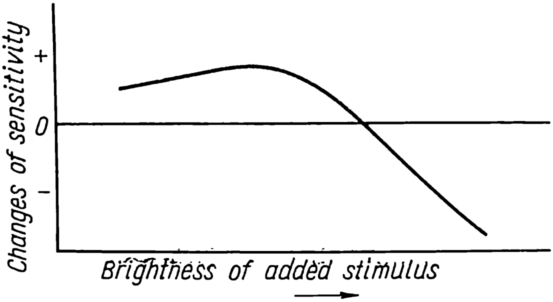

Fig. 16. Inverted effect of indirect stimulus conditional on latter's intensity in the relevant sensitivity (after Teplov)

ing intensity on green and orange photopic sensitivity. The sound stimulus was adjusted by registrable means from 25 to 95 decibels. Throughout this sufficiently wide range, the effects were constant, namely, sensitivity to green (530 mμ) increased, while sensitivity to orange (590 mμ) decreased. These opposing effects on various kinds of sensitivity grew with the intensification of the sound applied (Fig. 17).

Degree of excitation of the reacting organ. The effect of interaction between afferent systems depends, however, not only on the strength of the stimulus, but on the intensity of the excitation developing in the reacting organ as a result of its direct (adequate) stimulation. Lazarev stressed that a sound must be sufficiently loud *per se* for its intensity to increase under simultaneous illumination of the eyes. Otherwise the described effect may not be manifest, and there can even be a reverse response, i.e., sound intensity may be reduced by light.

Not only the strength, but the duration of indirect stimulation may be significant. The time factor may also influence the results of interaction between organs. Kravkov's ample experimental findings on the dependence of various visual functions on indirect auditory and olfactory

stimuli induce us to state that, as a rule, the latter's effect increases during the first minutes of their action. This increase, however, is not unlimited and is greater at onset than subsequently. If medium-power indirect stimulation continues more than 8-15 minutes, the effect is often

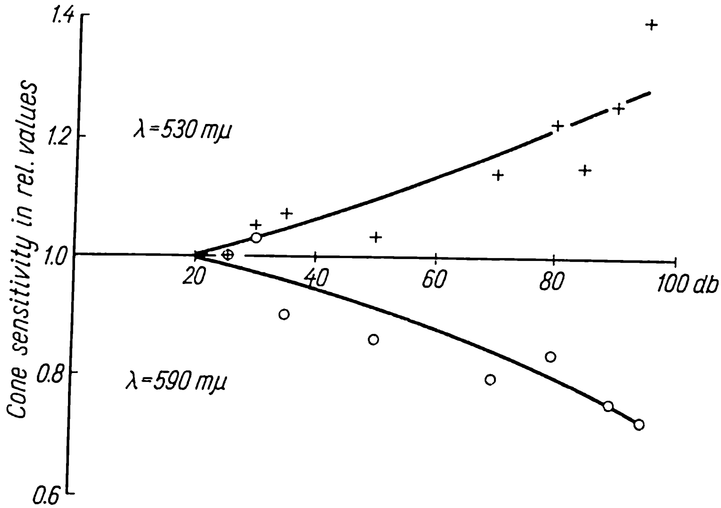

Fig. 17. Relationship between intensity of indirect auditory, stimulus and colour sensitivity (after Kravkov).
Abscissa: intensity of presented sound (775 cps) in db. Ordinate: colour sensitivity in relative values

reduced, i.e., passes a certain maximum. A vivid example of this kind is given in Fig. 18 showing the changes of c.f.f. for foveal vision elicited by rather loud indirect auditory stimulation.

Acoustic stimulation was carried on for half an hour (from the 31st to the 61st minute of dark-adaptation). The curve in Fig. 18 clearly shows how, under stimulation, the c.f.f. first grows drastically, then (approximately after 15 minutes of stimulation) begins to wane.

This raises the problem of adaptation to indirect stimuli, which, however interesting and important, has not been sufficiently investigated. Also awaiting elucidation is the problem of habit-formation in regard to indirect stimulation continuing through several days, which, with a high

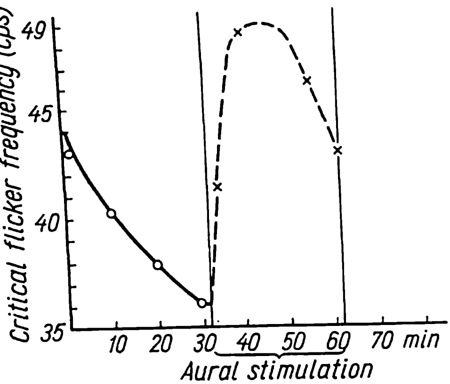

Fig. 18. Relationship between duration and effects of indirect stimulus. Changes in foveal critical flicker frequency under auditory stimulation (after Kravkov)

degree of certainty, may be of consequence for the effect of interaction.

Time factor. Sound reduces the c.f.f. for rod vision; subsequently, however, the c.f.f. increases under the same conditions, occasionally to a rather considerable extent (Kravkov). In a special work, Semyonovskaya demonstrated that scotopic sensitivity, which falls during indirect auditory stimulation, enters a phase of hyper-increase after cessation of the latter. The green-blue sensitivity of a dark-adapted eye increases when an anode is applied to the eyeball. After such inadequate stimulation is ceased, colour sensitivity not only falls to normal, but proves to be reduced (Kravkov and Galochkina). The effect of hyperventilation on colour vision (Kravkov and Schwarz) and c.f.f. (Rubinstein and Terman), likewise clearly reveals the existence of two action phases of opposite polarity. During inadequate stimulation the investigated function changes in a certain direction, which is reversed after stimulation ceases. Figs. 19 and 20 show the experimental findings of various authors on variations of critical flicker frequency under hyperventilation tabulated together with changes of scotopic sensitivity under D.C. stimulation of the eye.

The biphasic action of indirect stimuli is obvious from the drawings. The duration and vividness of the second phase, i.e., after-action, may vary considerably with concrete experimental conditions.

Emotional background. According to the findings of Schwarz, sound stimuli (various types of consonance) eliciting a pleasant effect, increase (in their after-effects) the sensitivity of a dark-adapted eye to the long-wave (orange-red) part of the spectrum and, inversely, reduce

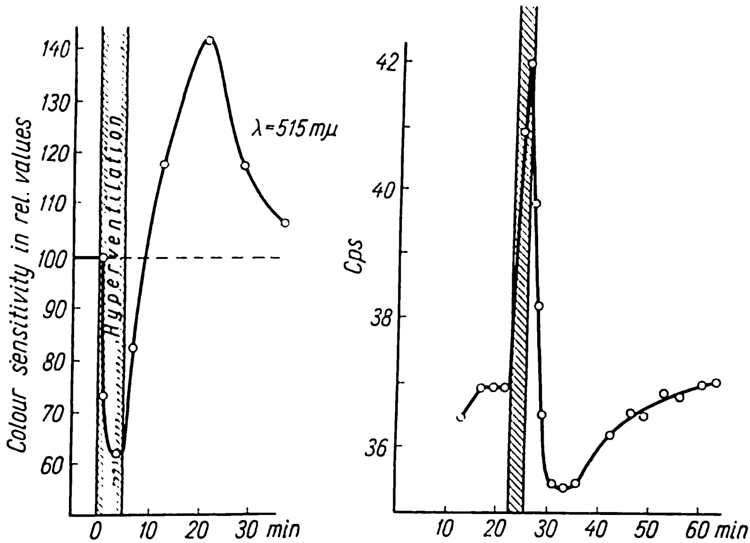

Fig. 19. Inverted action of indirect stimulus in its after-effects. Left—effects of hyperventilation on dark-adapted green sensitivity (after Kravkov and Schwarz). Right—effect of hyperventilation on critical flicker frequency for white flicker (after Rubinstein and Terman). Time denoted by hatched column

it in regard to short wavelengths. On the other hand, stimuli having a markedly unpleasant effect give rise to changes of an inverse order. Here we may recall an old observation by Dogil (already cited) who investigated changes in the vascular tone (plethysmograms) ensuing under musical acoustic stimulation.

The role of the psychophysiological background. Kravkov and Semyonovskaya encountered a vividly manifest case of background influence when investigating the effects of stimulation of various points in the peripheral retina on subsequent foveal sensitivity. As a rule, in all our subjects, including G., brief illumination of the entire visual field was succeeded for 30-50 minutes by a noted increase of foveal discriminatory sensitivity in conditions of very low brightnesses. In one experiment under strictly identical conditions, however, G., revealed not an increase, but a considerable and prolonged reduction of subsequent discriminatory sensitivity. As it turned out, the subject had been in very low spirits that day because of family circumstances.

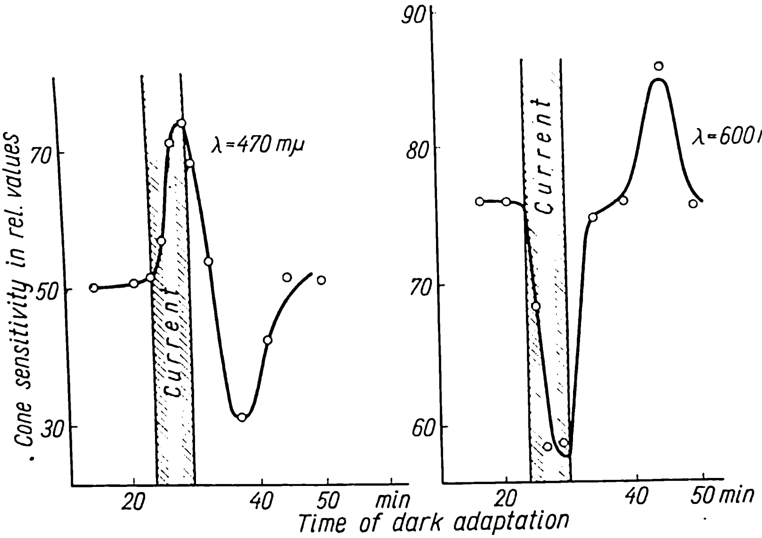

Fig. 20. Inverted action of indirect stimulus during its after-effects. Changes in dark-adapted cone sensitivity under anelectrotone (anode on eyeball) (after Kravkov and Galochkina).
Abscissa: time of dark adaptation in minutes. Ordinate: cone sensitivity in relative values. Current action time denoted by column.

Schwarz observed that the prolonged effects of coloured lighting tell upon aural sensitivity; green light increasing and red reducing it. This regularity (observed in all six subjects) may, however, be reversed if we change the subject's general physiological condition, i.e., the background on which the colour stimulus acts. In Schwarz' experiments this was done by means of moderate doses of veronal, a soporific agent. Under the latter's effects green light reduced auditory sensitivity, whereas red light increased it. Although, generally speaking, the resultant changes in auditory sensitivity were less than observed normally, they reached up to 25-30 per cent of the initial level and, what is most important, developed in a different direction. To put it otherwise, in normal conditions red light has an unpleasantly irritating effect, whereas in drug-induced somnolence it may act as a pleasant tonic.

Conjoint effects of several indirect stimuli. To conclude, we should like to draw attention to the following. Almost all research carried out to date on the interaction of sense

organs was purposed to clarify the effect of a single indirect stimulus on a given function of the sense organ under study. In real life, though, people are usually subject to the effects of a whole combination of indirect stimuli, which may differ in intensity, but affect us simultaneously. Doubtlessly, the particular effects of these stimuli may be different and even contradictory in nature. The relevant changes in the function under study present the summary result of a number of such influences. Hence the need to investigate the combined effects of several indirect stimuli. As far as we know, there have been no special works on this subject. All we may mention is the research carried out in our laboratory by Semyonovskaya who made several experiments dealing with the combined influence of illumination of various retinal areas and concomitant sound stimulation on scotopic after-sensitivity.

CONCLUSION

As demonstrated in our laboratory, inhibition is usually followed by a period of hyperexcitability. Numerous experiments by Kravkov and Semyonovskaya, Vishnevsky,

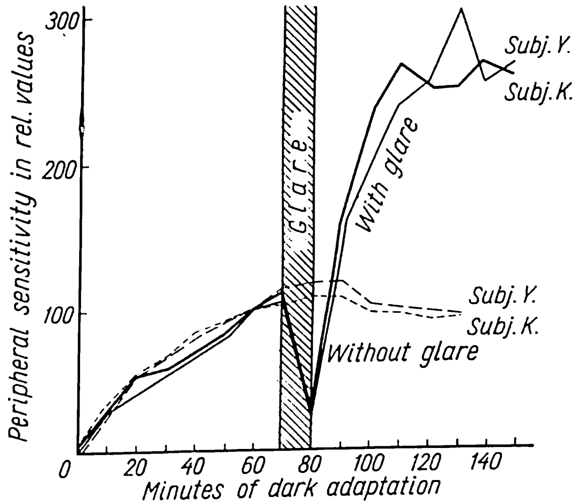

Fig. 21. After-effects of red glare on peripheral sensitivity (after Kravkov and Nikiforova). Findings for two subjects

Rosenblum and Streltsov have established that a definite dose of light stimulation applied to the entire retina or its central part (so-called glare) may elicit a notable increase of rod after-sensitivity. Especially striking effects are obtained by red light. Fig. 21 shows the results of experiments in which the eye was illumined with red light at what would normally be the maximum of sensitivity, i.e., on the 70th minute of dark adaptation.

Thus, scotopic vision may be sensitised. In practice, especially under war-time conditions, such a heightening of scotopic sensitivity may doubtlessly prove useful. No wonder the problem of red glare attracted the attention of foreign researchers in the last war. As we have seen, the results of such research (Rowland and Sloan, Hecht and Hsia) merely confirmed the facts revealed 10 years ago by Semyonovskaya and ourselves. As a direct practical outcome of these discoveries, R.A.F. manuals instructed British pilots to stay in a lighted room wearing red goggles for a certain time before night flights. We may also mention the findings of Seitz and Orlansky on optimum cockpit lighting. According to these authors, with an illuminance of 7 luxes, red lighting ensures a fourfold gain in scotopic after-sensitivity as compared with white lighting.

MANUAL INTERACTION IN THE PROCESS OF TACTILE PERCEPTION*

By B. F. LOMOV

(Leningrad University)

1. GENERAL CHARACTERISTICS OF BIRECEPTION

One of the basic features of haptics, as of other sensory systems, is the existence of twin receptors (bireception).

As demonstrated by studies on binocular vision, binaural audition and dirhinic olfaction, the existence of twin homonymous receptors is a special device of the sensory systems playing an important part in *spatial discrimination* (1).

But this is not the only factor determining the vital importance of bireception. Another function of twin homonymous receptors is mutual control and correction of signals transmitted by either receptor as well as intersubstitution (in cases of impairment of one of the receptors or difficulties in perception). Thus, bireception ensures a high level of *reliability* in the work of the sensory systems.

The problem of *bireception* forms part of the more general problem of the *twin structure of the hemispheres,* first raised by N. Y. Wedensky (13). Wedensky revealed that stimulation of a cortical centre in one hemisphere is inevitably accompanied by desensitation of the homonymous centre in the contralateral hemisphere, i.e., the relationships between homonymous centres are governed by the law of induction of nervous processes.

Later Pavlov (7) and his collaborators showed hemispheric interaction to be subject to the law of irradiation.

At first glance, these conclusions seem mutually contradictory. But the contradiction is only apparent, for in fact, hemispheric interaction is a *process* in which

* The article is an abridged translation of a chapter from the book *Tactile Perception in the Process of Cognition and Labour*, ed. by V. G. Ananyev, Moscow, 1959.

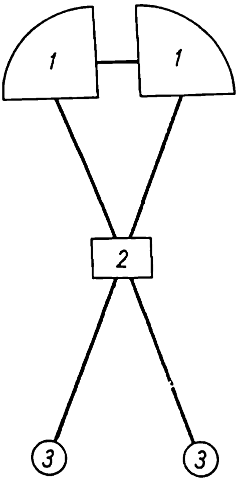

Fig. 1. Schematic diagram of bireceptor analyser:
1—cerebral terminal of analyser uniting projection zones in both hemispheres; *2*—crossing of afferent paths; *3*—twin receptors

phases of induction alternate with irradiation and vice versa, the phasic alternation being determined by concrete conditions of analyser activity.

Anatomic, physiological and psychological investigations on bireception lead to the conviction that any of the homonymous receptor pairs presents a bifurcating peripheral ending of a *single* analyser (and not of two analysers). Thus, each analyser is *bireceptory*. Its cerebral terminal, comprising a system of nuclear and diffuse cells, unites symmetrical points in either hemisphere. Afferent pathways connect the cerebral terminal with a pair of symmetrically localised receptors (Fig. 1).

Functional investigations of the visual, auditory, kinaesthetic and olfactory analysers carried out in the Leningrad University under the guidance of Prof. B. G. Ananyev, showed that twin receptors are characterised by *functional asymmetry*. It was established that under definite conditions of spatial discrimination, one side of the analyser plays a leading or dominant role, i.e. there is a leading ear, eye, etc. It was shown, further, that functional asymmetry is *not univalent*, and may *vary*. Thus, the eye which is dominant in visual acuity, may not be so in regard to its sighting function, etc.

Experimental findings allow us to consider that functional asymmetry is of conditioned-reflex origin, determined by spatial conditions of sensation and perception.

2. MANUAL FUNCTIONAL ASYMMETRIES AND THEIR ORIGIN

The functional division of the right and left hands is a major feature in the motor development of man. In the majority of people, the right hand is dominant in work-activity, which phenomenon is known as right-handness.

Individuals with left-handness are rare, while ambidexters or symmetrics equally well managing their right and left hands are still rarer.

The functional division of the hands evident in human activity, finds its reflection in the characteristics of the motor analyser, one of whose sides, as a rule, proves dominant. In particular, G. P. Pozdnova established that the right hand of right-handed individuals is dominant as regards spatio-motor orientation (8). On the contrary, as regards weight perception, the dominant role in right-handers belongs to the left hand.

The non-univalence of manual functional asymmetry is still more apparent when we compare their vibratory, tactile and temperature sensitivity, as well as the speed and precision of tactile perception.

According to D. A. Stavrova, in the majority of cases, the vibratory sensitivity of the left hand (in right-handers) is higher than in the right (11).

As evident from our own experiments, a similar picture is observed in tactile discrimination of the area of objects applied to the palm.

A. V. Rykova found that the temperature sensitivity of the motor-dominant hand is lower than that of the contralateral organ. Her experiments also demonstrated that the sensitivity of the dominant hand increases during the elaboration of a conditioned sensory reflex by the combined presentation of cold and the sound of a metronome. When the reflex is elaborated via the non-dominant hand, the latter's temperature sensitivity shows a decrease. During the experiments, the conditioned reflexes and relevant differentiations were transferred from hand to hand without additional presentations. This confirms that the relationships which Pavlov's school discovered in animals are also valid for man. However, if in animals the transfer of conditioned reflexes from one side of the body to the other is completely identical with transfer in the reverse direction, the same process in man reveals asymmetry. According to Rykova, conditioned skin reflexes to sensitisation are transferred from the dominant hand to the non-dominant, and responses to desensitisation—vice versa.

In collaboration with A. V. Idelson, we established that the time spent on palpating the same simple objects with the left hand (in right-handers) is often shorter than with

the right, although the formers' precision is higher. In our experiments, left hand dominance in palpation time occurred in 66 per cent, right hand dominance—in 27 and equality in 7 per cent of all cases.

Thus, the hands are asymmetric as regards their sensory and motor functions. The degree of asymmetry for various functions is unequal. A cardinal feature of functional manual asymmetry is the contrast relationship between kinaesthesia and various kinds of cutaneous sensitivity. The hand which is dominant in motor sensitivity and space-motor orientation, is often non-dominant as regards tactile, vibratory and temperature sensitivity.

However, the functional asymmetry of the hands does not imply functional independence. The very division between the hands can be understood only by analysis of their interaction. I. M. Sechenov (1902) first showed that the conjoint activity of the hands, and hence of the respective hemispheres, is a major requisite for each hand to be able to work separately. Later this was confirmed by many authors.

Investigations by V. Y. Bushurova and N. P. Golubeva showed that manual functional asymmetry (as regards motor activity) emerges as a consequence of motor development (3, 5). Its first signs appear at the age of 4-5 months. Initially, it is rather unstable, but as the child learns to walk and manipulate with various objects, the division of manual functions becomes more and more manifest.

The findings of these and other authors allow us to presume that functional asymmetry is linked with certain congenital factors, which, apparently, are associated with the role of labour in the evolution of man. As is known, functional asymmetries are specific to man alone, certain rudiments being evident in anthropoids. The division of manual functions is originated by the necessity of manipulating implements and objects of labour simultaneously. In the course of evolution, the right hand predominantly specialised in manipulations with implements of labour, which accounted for the dominant development of its motor functions. The left hand, conversely, specialised in manipulations with the object of labour, which determines its dominance in regard to certain sensory functions.

A confirmation of the hypothesis of the labour origin of manual functional asymmetry may be found in the works

of the archeologist S. A. Semyonov, who succeeded in reconstructing certain primeval work-acts (10).

It may be presumed that the division of manual functions in the work-act led to the development of functional asymmetries in all other sensory systems.

3. ELECTROPHYSIOLOGICAL DATA ON HEMISPHERIC INTERACTION IN MAN

Direct proof of hemispheric interaction during the isolated work of each hand was obtained by A. V. Idelson (6) who applied electroencephalographic techniques.

The subjects were assigned the following tasks of varying complexity: 1) to move the wrist and fingers of the left hand; 2) to move the wrist and fingers of the right hand; 3) to perform the same act with both hands; 4) to feel a flat figure with the left hand until its exact image is obtained; 5) to do the same with the right hand. The action potentials were taken from bipolar electrodes applied to symmetric points on the skin of the head in random parietal or occipital areas. Three subjects were investigated by means of monopolar leads.

Analysis of the EEG showed that isolated movement of one hand is accompanied by changes in the electrical activity of both hemispheres. Substantial inhibition of the alpha-rhythm was noticed.

However, isolated movements of the right hand (in right-handed individuals) were followed by more considerable changes in the electrical activity of the contralateral hemisphere than with isolated movements of the left hand, which is accounted for by manual motor asymmetry.

When the figures were felt with the left and right hands, electrical activity was roughly equal in both hemispheres.

Unihemispheric activity during isolated acts of both hands was not observed at all.

It is assumed in electrophysiology that variations of action potentials reflect the relationships between inhibitory and excitatory processes of various origin (conditioned and non-conditioned).

The findings of A. V. Idelson give convincing evidence that the unequal processes arising during isolated manipulations by any one hand irradiate to both hemispheres.

Comparing the EEG obtained during the performance of various assignments, Idelson established that the degree of irradiation of nervous processes is directly dependent on the complexity of the assignments. The more complex the latter, the more intensively the nervous process irradiates from hemisphere to hemisphere, and the more intense the activity of the cerebral cortex in general.

Analysing the EEG obtained with monopolar leads, he revealed certain new facts concerning the spatial dynamics of nervous processes.

Various phases of voluntary monomanual acts are accompanied by varying changes in the electrical activity of both hemispheres. The initial and final stages are marked by profound inhibition of the alpha-rhythm in all cortical areas (frontal, parietal, and occipital). In the intermediary stage, as a rule, alpha-rhythm inhibition is noted in the parietal and occipital areas only of the contralateral hemisphere (Fig. 2).

Idelson explains the electrical changes noted in the intermediary phase by the automatisation of the assigned voluntary movements.

Evidently, the "symmetry" of electrical activity in the beginning of the movement of one hand is conditioned by irradiation of excitation from one hemisphere (contralateral) to the other (ipsilateral). In the intermediary stage the excitation concentrates in a focus localised in one hemisphere (in left-hand movements—in the right, and in right-hand movements—in the left). This, according to the law of induction, leads to inhibition in the contralateral hemisphere. At the end of movement—when motion is followed by repose—the excitatory process is evidently irradiated again.

Thus, changes in electrical activity are linked with the phasic alternation of the processes of induction and irradiation in both hemispheres.

The greater electrical activity of the frontal lobes in the beginning and end of movement is regarded by Idelson as indicative of the regulatory action of the second signal system on the first.

The entire process of monomanual tactile perception of simple figures is accompanied by electrical activity throughout the cortex. The frontal lobes of both hemispheres reveal the most intense activity mainly in the first half of

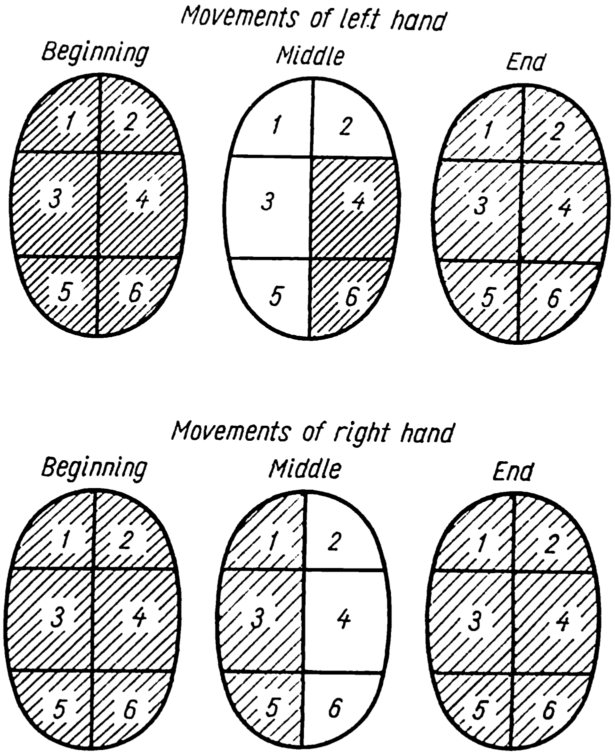

Fig. 2. Diagram of changes in electrical activity (after A. V. Idelson):
1 and *2*—frontal lobes of right and left hemispheres, *3-4*—parietal lobes of right and left hemispheres; *5-6*—occipital lobes of right and left hemispheres; hatched sections—areas of alpha-rhythm suppression

the perceptual process. This is explained by the verbal nature of the assignment (instructions) and the important role of speech-motor mechanisms in the process of perception. The electrical activity of the parietal lobes depends on which hand takes part in the process of perception. If it is the right, they are active throughout the process, the left lobe being more active during its second half. Conversely, with the left hand participating alone, the parietal lobes of both hemispheres are less active in the latter half than in the beginning of the process. This,

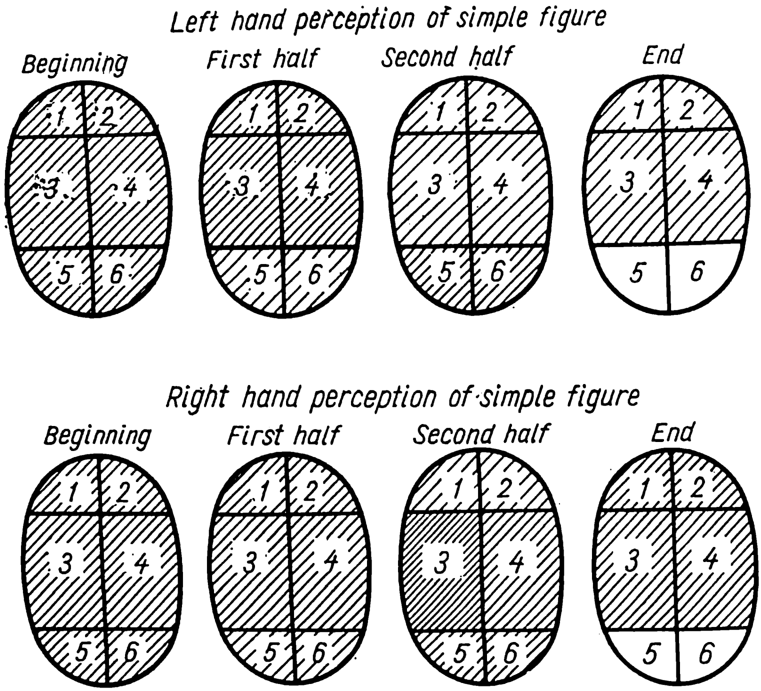

Fig. 3. Spatial dynamics of cortical electrical activity (after A. V. Idelson):
Symbols as in Fig. 2. Maximum alpha-rhythm depression denoted by denser hatching

evidently, is a manifestation of the specific features of manual functional asymmetry.*

As regards the perception of simple figures, maximum occipital activity in both hemispheres is noted during the latter half of the process (Fig. 3).

Apparently, occipital involvement in the electrical changes is linked with the visualisation of the tactile image. Occipital as well as frontal activity is the greater, the more complex the figure being perceived.

In monomanual tactile perception of complex figures, the entire cortex acts still more intensively. In this case the electrical activity of symmetric lobes in each of the

* We may recall that left hand palpation proceeds with greater speed and precision than in the case of the right hand.

hemispheres changes equally during both right- and left-hand palpation, i.e., functional asymmetry is not observed. Comparing the dynamics of electrical activity in both hemispheres during simple voluntary movements and tactile perception, we find more profound interaction in the latter process.

Apparently, the phasic alternation of nervous processes during tactile perception is subject to complex laws.*

Additional data on hemispheric interaction during isolated monomanual acts were obtained by M. S. Bychkov (4) and V. N. Semagin (9).

Investigating cortical bioelectricity during the ideomotor act, Bychkov established that imaginary work by the right hand only is accompanied by potential changes in both the right and left zones.

Semagin's experiments revealed potential changes in the deltoids of both arms during monomanual action.

All these findings testify that the isolated work of one of a pair of kinaesthetic receptors is accompanied by the conjoint work of both hemispheres.

4. SPECIFIC FEATURES OF BIMANUAL TACTILE PERCEPTION

The problem in question was first posed by B. G. Ananyev. Together with A. Davydova (1949) [2] they investigated the bimanual perception of plane figures in specified experimental conditions, viz, the subject was to palpate the figure with both hands, one hand investigating one side of the figure, and the contralateral hand simultaneously palpating the other, without any stops in the movement of either hand (synchronous bimanual tactile perception). The authors revealed that the binohaptic image forming in such experimental conditions is extremely labile and unstable. The image undergoes duplication (splitting), as is the case in binocular vision with sharp disparity. The sensory interaction of both hands in the perception of plane figures is marked by drastic motor asymmetry.

Ananyev and Davydova investigated but one of the cases of bimanual perception, namely, synchronous palpation of

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* Idelson was able to measure the duration of cortical potential changes only with a precision of up to one sec. More precise analysis of these changes (up to a fraction of a minute) should give a better idea of the phasic dynamics of these processes.

plane figures. As it is, though, bimanual perception is not limited to the stated case. The problem of bimanual perception incorporates a wide range of questions concerning manual interaction in different perceptual conditions. Subsequent investigations showed bimanual perception to possess a number of specific features and advantages as compared with monomanual.

First, the *tactile field* in bimanual figure perception is considerably *wider* and more perfect than in monomanual.

Special experiments in which subjects were asked to feel large figures first with one and then, a few months later, with two hands, demonstrated that the tactile field of one hand is insufficient for the perception of large-size objects. In this case the tactile signals become unstable, which distorts the image, the object's proportions and the relationships between its parts. A similar picture is evident when we compare bimanual and monomanual perception of small volumes or areas with complex outlines.

The experiments show that the need for employing monomanual or bimanual perception is determined by the size and complexity of the object. With the increasing size and complexity of the object, monomanual perception becomes cumbersome and inexact. The tactile field of one hand in such conditions becomes inadequate, proving too narrow for the perception of large volumes and areas. The necessary extension of the tactile field is obtained by interaction between both hands. The bimanual tactile field exceeds the monomanual in all dimensions (sagittal. ventral and frontal).

Judging from the diagrams* and accounts made by subjects, constriction of the tactile field primarily affects the synthesis of tactile signals. These difficulties should account for the fact that some of the object's details fall out, its proportions are inadequately reflected and the image, in the subjects' words, is not integral. The advantages of bimanual palpation are manifest in such a major parameter as *speed* of perception.

The greater speed of perception in bimanual operation is accounted for by a number of circumstances. As evident from comparison of monomanual and bimanual object palpation, the former proceeds 1.5-2 times longer than the latter. First, the amount of simultane-

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* The structural principles employed in most experiments were identical: the subject (blindfolded) was asked to feel a certain figure and then draw it. The time spent by the subject was noted, and the movements of the hands were registered by a film camera.

ously arriving tactile signals increases, which creates more favourable conditions for differentiating the formal peculiarities of the object. True, under certain conditions (synchronous palpation of asymmetric objects) the numerical increase of signals causes a series of difficulties (see §§ 7 and 8).

Further, manual interaction provides for *economy* of tactile movements. As evident from analysis of motion pictures and observations, monomanual perception involves a multitude of return and repetitive movements. In bimanual tactile perception, such movements are considerably fewer.

At the same time, manual interaction provides for a greater variety of conjoint tactile movements.

The high variability of conjoint manual movements, besides creating conditions for fine discrimination of the object's contours, ensures economy of time, i.e., accelerates tactile perception.

Finally, manual interaction permits the perception not only of isolated objects, but also of *spatial relationships between them*.

The distinctive aspects of manual interaction in the process of tactile perception were studied by ourselves in collaboration with A. V. Idelson. During the experiments, the subjects were asked to feel three-dimensional and plane objects placed behind a lightproof screen. In some cases the subjects felt objects held in their hands, in others the objects were secured to holders.

The experiments established that bimanual perception is marked by sharp division between the functions of both hands. In cases when the object had no natural support (was held in the subject's hands), the left hand (in right-handers) performed a supportive function, holding the object in a fixed position chosen by the subject. Perception, i.e., the sensory function proper, is effected in this case by the right hand alone. The left hand only seldom, from time to time, shifts or rotates the object, placing it in a position most convenient for the tactile movements of the right hand.

In cases when the object is secured to a holder, the nature of interaction between the hands alters. The left hand ceases to act as a support and participates in the tactile process more actively. Yet in this case, too, there is a division in the functions of the two hands, although of a somewhat different character. One of the hands

assumes mainly the function of a point of reference (similar to the thumb in monomanual perception), fixating a corner or rib, less often a facet of the object of perception. The other hand consecutively moves along its surface (similar to the index and middle finger in monomanual perception).

The division in manual functions, however, presents a variable, depending on the shape of the object and the stage of tactile perception. During perception of three-dimensional objects, in the initial stage, the left hand usually fixates the point of reference (mostly, the left lower corner), while the right hand consecutively feels the "right" side of the object. At the end of the process the hands exchange functions: the right fixates the point of reference (usually the right lower corner) and the left palpates the "left" side of the object. At every given moment of perception the hands are placed on opposite facets of the object (separated by the third dimension so to speak) similar to the way the thumb and index finger are arranged during monomanual perception of three-dimensional objects. In the case of plane figures, the hands exchange functions considerably more often.

At any given moment in the perception of asymmetric plane and three-dimensional objects, only one hand is in motion, while the other is at rest, fixating some initial point of reference. The moving hand appraises the palpated part of the object in relation to the said point. Thus, the interacting hands present a unitary coordinate system similar to that observed in monomanual perception (13). However, the coordinate system of interacting hands is more complex and dynamic than the latter. It contains twice as many elements and possesses an additional measurement scale (the distance between the hands). The conjoint movements of the hands are more varied in form than the conjoint movements of the fingers on any one hand.

5. THE PROCESS OF BIMANUAL PERCEPTION

The process in question consists of three main phases:

1) orienting (or setting) movements of the hands;

2) primary palpation (primary consecutive exploration of the object's contour);

3) repeated palpation (secondary consecutive exploration of either the entire contour or its most complex sections).

The initial movements of the subject's hands are to be regarded as spatial *orientation* in the tactile field.

Both hands move simultaneously in the air or over the table surface along the body's sagittal axis, alternately approximating or moving away from each other until contact with the object is established. After that, the hands glide over the object's surface up to the extreme superior point. The light orienting movements of the hands along the object's surface are controlled by tactile sensations coming, chiefly, from the middle fingers, which move ahead of all the rest. Having reached the extreme upper point, the middle and index fingers touch one another, performing a multitude of minute movements. Then both hands assume a position most convenient for tactile movements, and for some time (from 0.2 to 1.5 seconds) *fixate* the extreme upper point of the object, which serves as the point of reference, i.e., the point of manual divergence.

By means of such orienting movements the subject determines the localisation of the object in the tactile field in relation to his own body. All further tactile movements are directed towards analysis of the form (or contour) of the object.

Almost any object (except the most simple) is felt twice, and sometimes thrice. The time of repeated palpation is 1.5-2.5 times shorter than primary palpation. Repeated palpation involves fewer fingers, and there are almost no return movements (which will be dealt with further). Very often the direction of movement in secondary palpation is the opposite of that observed in primary palpation.

In order to elucidate the role of repeated palpation, the tactile process was interrupted in some of the experiments, and the subject was asked to draw the object after primary palpation. Judging from the drawings, the image in this case proved to be unstable and vague (Fig. 4).

By and large, in primary palpation, the object's contour is reflected with relative correctness, but individual details and, chiefly, the distances between them are distorted. Often, the object is pictured as somewhat drawn out along the vertical axis. It is interesting that after primary palpation the subjects drew the details of the object in the sequence in which they perceived them manually. The experimenter's request to change the sequence of drawing caused difficulties. This testifies to the influence of the

sequence of tactile signals on the image of the contour, and speaks of their incomplete synthesis. Apparently, the purpose of primary perception is to analyse the details of the contour, to break it up into component parts. Synthesis of tactile signals at this stage of the process is incomplete,

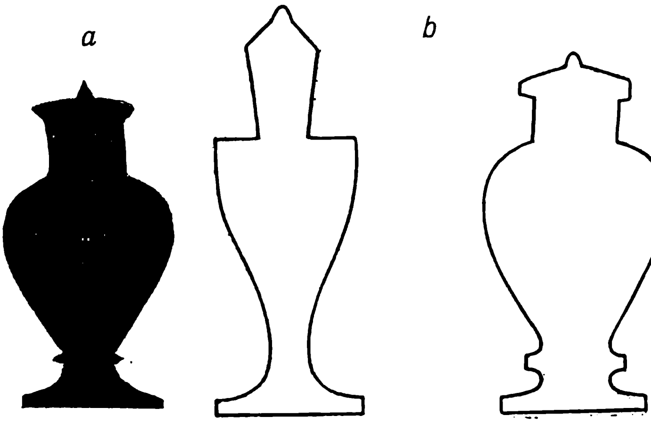


Fig. 4. Subject's drawings after primary and repeated palpation of object: *a*—object; *b*—subject's drawings

partial. More or less clearly reflected are the relationships between those parts of the contour which lie in the zones of manual divergence and convergence.

At repeated palpation, conversely, the synthesis of tactile signals is the primary task. Analysis here plays a secondary part, serving to modify certain contour elements. The direction of repeated tactile movements is in most cases the opposite of that observed in primary palpation. The change in direction is accompanied by a change in the sequence of tactile signals arriving from the same parts of the object. This, apparently, creates the most favourable conditions for integrating the space-time components of tactile perception into a unitary spatial image of the object, i.e., for synthesis of tactile signals. After repeated palpation, the subject can usually draw the contour details in any order suggested. Apparently, the changed direction of repeated tactile movements com-

pensates the influence of the sequence of tactile signals on the image.

Another function of repeated palpation is control of the results of primary palpation.

The movements of the hands along the surface or contour of the object are requisite for the analysis and synthesis of tactile signals.

Shot-by-shot analysis of films disclosed the complexity of movements performed during the tactile process.

Most vividly differentiated are the movements involved in consecutive exploration of the object—*the tactile movements proper*. Their magnitude and path are determined by the size and shape of the object. Alongside, or, more exactly, within these movements, we may note a multitude of *micromovements* performed by each digit. Analysis of motion pictures established that the point of contact between a finger and the object shifts cyclically in the process of tactile perception, whereby new areas of the skin receptor are successively involved. The magnitude of such shifts is small, usually not exceeding 1-2 mm, yet their importance is apparently quite considerable. It is known that prolonged stimulation of the same areas of the skin receptor sharply reduces their sensitivity. The constant change of contact points is evidently indispensable for maintaining tactile sensitivity at a definite level, and, probably, for raising it as well.

The tactile micromovements of the fingers perform an adaptive function, ensuring the change of contact points, whereby skin sensitivity is maintained at a constant level. These movements, by creating additional friction (added to the friction arising at consecutive palpation of the contour), likewise serve for fractional analysis of the texture of the object being palpated.

Despite the importance of digital micromovements, they perform a supplementary role in the tactile process, sustaining tactile sensitivity. The basic role in contour reflection belongs to movements involved in *consecutive exploration*. By and large, the dominant role in contour reflection belongs to kinaesthetic analysis of the path of movement of each hand. Provided there is continuous contact with the object, the path of manual movement exactly corresponds to the contour of the object being palpated. However, an adequate image of the object cannot

be formed by arbitrary contour palpation. If the movements are too swift or too slow, the resulting image is usually distorted. Hence, adequate tactile reflection requires movements of an optimum speed approximately equalling 5-10 cm per second.

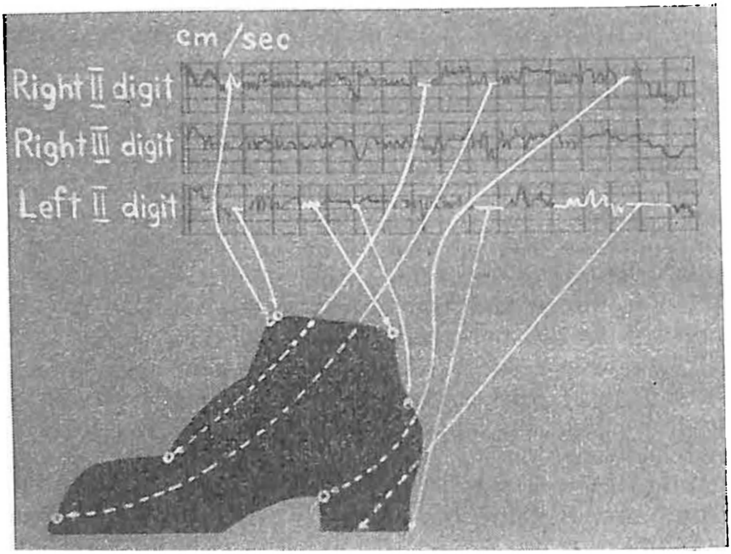


Fig. 5. Top—speed graphs of II and III right hand digits and II digit of left hand. White lines—intervals in movement; return movements plotted below abscissa. Circles mark pauses of hand movement on contour

The tactile movements of the hands are not smooth and continuous throughout. A single movement of each hand along the contour is clearly divided into a number of laps corresponding to the number of contour elements. Analysis of films clearly shows the pauses occurring in the movements of the hands. The pauses fall on contour sections (chiefly, angular apices), where the hands change their direction (Fig. 5).

The successive alternation of movements and pauses is necessary for dismembering the contour elements. In the given instance each pause signifies the end of one and the beginning of another line, enabling the subject to differen-

tiate successive movements. The duration of pauses in the movement of each hand depends on the movements of the other hand. If one of the hands reaches the end of the palpated line earlier than the other, it stops to "wait" for the other hand to reach the end of "its" line. A certain

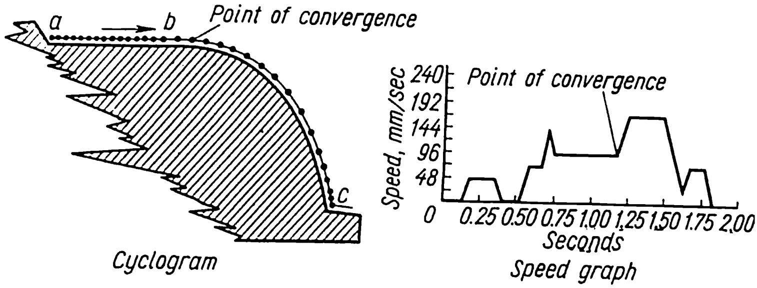


Fig. 6. Cyclogram and speed graph of right-hand movement during palpation of contour element (convergence). Dots on cyclogram denote shots: dots along line *ab* are denser (i.e., speed is less) than along *bc*. Arrow shows direction of movement. Abscissa: time; ordinate: speed of hand movement. Evidently, changes in hand speed facilitate discrimination of curvatures and points of convergence

time (0.2-0.3 seconds) is occupied by a pause in the movement of both hands, after which they begin the next movement. The synchronism of pauses, is apparently important for evaluating the proportions of the contour and the magnitude of its lines.

Such a picture is clearly evident from analysis of the process of perception of contours or contour elements consisting of straight lines, where the line-to-line transition is clear-cut.

A somewhat different picture arises in the palpation of convergencies, which are marked by smooth line-to-line trasition. In this case there are no clear-cut pauses at the moments of passage from line to line, but the hands exhibit more or less vivid changes of speed as they reach the points of convergence: the greater the curvature, the higher the speed of tactile movements (Fig. 6).

Analysis of manual interaction in the process of bimanual perception reveals the temporal characteristics of

their movements to be dependent on individual features of the contour in question.

The process of manual interaction develops in different ways, depending on whether the investigated object is symmetric or asymmetric in relation to the vertical axis.

When palpating *symmetric* figures, the movements and pauses of both hands are *synchronous*. At each given moment of perception the hands are placed on symmetric points of the contour. The synchronism of manual movements apparently ensures discrimination of the identity of the right and left halves of the contour. The length, position and shape of lines on both halves are evaluated in relation to the axis of symmetry. The synchronism of perceptual movements is typical only for such figures whose axis of symmetry lies vertically, i.e., parallel to the subject's ventral body axis. The slightest change in the figure's position (e.g., a shift of the axis into a horizontal plane), is followed by sharp changes in the tactile dynamics: the movements of the hands become asynchronous. This fact may be understood only in the light of the structural features of the bimanual tactile field, which is sharply divided into a left and right half by a vertical line passing through the points of manual divergence and convergence.

In the perception of *asymmetric figures* the hands stop alternately, each in turn assuming the function of a mobile point of reference, i.e., the movements of the hands are *asynchronous*. The constant alternation of movements and pauses in each hand makes it possible to determine the proportions between individual parts of the asymmetric figure. The position, length and shape of lines palpated by one hand are appraised in relation to the points fixated by the other hand. Attempts to move both hands synchronously cause difficulties in the elaboration of an integral image. The nature of these difficulties is described in detail in § 7.

In the perception of complex contours consisting of symmetric and asymmetric components (in relation to the vertical axis), the temporal characteristics of conjoint manual movements vary constantly: symmetric elements are palpated synchronously, and asymmetric ones asynchronously.

In the process of bimanual perception the tactile analyser performs a dual task, including discrimination of successively arriving signals from each hand (1) and of signals simultaneously arriving from both hands (2).

In order to form an adequate image of symmetric contour elements, in conformity with the demands of geometry, the hands must lie at every given moment of perception on different sides of the axis of symmetry, on the same perpendicular to the latter and at equal distances from the perpendicular's base. This is possible only if the movements of the hands are synchronised. In this case the tactile signals arriving simultaneously from the right and left hands are identical (or, more precisely, the signals from one hand are mirrored reflections of those coming from the other). The identity of simultaneous tactile signals ensures correct reflection of the identity of the right and left sides of symmetric figures.

Here, in point of fact, the function of discriminating simultaneously arriving signals is cancelled. The main task of the tactile analyser in synchronous perception is to discriminate successively arriving signals, which, as a rule, are unidentical. When palpating asymmetric figures, it has to discriminate successive as well as simultaneous signals from both hands. The complexity of the task facing the tactile analyser in this case underlies the complex dynamics of conjoint bimanual movements. If pauses in the movement of hands are necessary for discriminating successively arriving signals, the pauses of one hand during the movement of the other are needed to discriminate signals arriving simultaneously. The asynchronism of movements is thus requisite for discrimination of simultaneous tactile signals.

Analysis of films established that when palpating complex contours the hands frequently perform *return movements*. The direction of these movements is the reverse of those involved in consecutive exploration of the entire object.

Their speed is somewhat higher than the average (Fig. 7).

Return movements are obligatory in the palpation of contour lines differing but slightly from the preceding elements. So, in Fig. 7, line AB is straight, while BE shows a slight curvature.

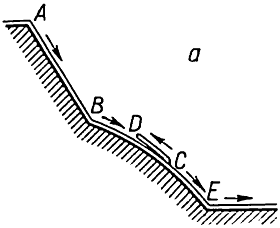
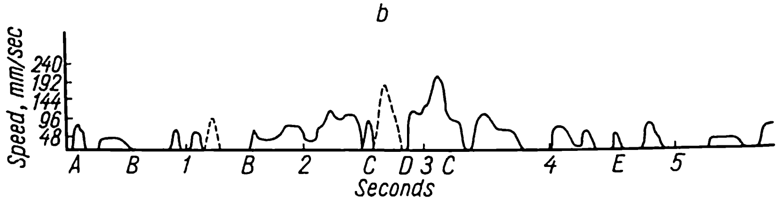


Fig. 7 a—path of right hand along part of contour; *b*—speed of right-hand movement. Dash line—speed of return movements



As a rule, the less the difference between successive contour lines (in the order of palpation) the more frequent are return movements. Direct movement results merely in very coarse differentiation of successively arriving signals. The discrimination of directions of motion is comparatively precise, but the length, shape and position of contour lines in respect of the vertical axis are differentiated less exactly. Return movements provide for better discrimination of all features of the palpated lines.

In the perception of symmetric contour elements, return as well as direct movements are simultaneous in both hands. In the case of asymmetric elements, the situation is different, viz., the return movement of one hand corresponds to a total and strongly manifest continuous pause in the movement of the other hand.

The dynamics of tactile perception are determined by the features of the contour and its position in the bimanual tactile field in relation to the points of manual convergence and divergence. The points of line-to-line transition are marked by distinct pauses or intervals in the movement of the hands. These pauses are requisite for the discrimination of successively arriving tactile signals. The less the difference between successive contour lines, the more movements and pauses are needed for their differentiation.

When palpating slightly differing lines, the hands perform return movements which serve for fine differentiation (and simultaneously for the formation of stable associations) between successively arriving tactile signals. If we consider that each manual excursion is accompanied by excitation of the cerebral end of the kinaesthetic analyser, while a pause corresponds to inhibition, we must acknowledge that the process of tactile perception is accompanied by a most complicated picture of neurodynamic developments. The excitatory phases of the kinaesthetic analyser are constantly succeeded by inhibition with a frequency and sequence determined, in the final issue, by the spatial features of the figure in question. Since pauses in the tactile movements are necessary for the discrimination of successively arriving tactile signals, it may be considered that the inhibition corresponding to a pause is of differentiating nature.

In dealing with symmetric figures, the processes of excitation and inhibition in both hemispheres arise and alternate synchronously, since the movements and pauses are simultaneous in both hands. Apparently, the dynamics of nervous processes in this case are determined chiefly by the action of the law of irradiation. When dealing with asymmetric figures, hemispheric interaction bears a different aspect. In this case the movement of one hand is usually concomitant with a pause of the other. The combination of movements and pauses is necessary for discrimination of simultaneous tactile signals, and the finer the discrimination of signals from one hand, the more marked are the pauses in the other. During the palpation of asymmetric figures, hemispheric interaction is dynamic, including a continuous succession of alternating phases of irradiation and induction. In the final analysis, the dynamics of hemispheric interaction are determined by the spatial conditions of bimanual perception (spatial features of the figure proper and its position in the tactile field).

6. DIGITAL INTERACTION IN THE PROCESS OF BIMANUAL PALPATION

Comparative analysis of the movements of each digit and the entire hand revealed the following major fact. When palpating individual contour lines, the movements

of the hands are relatively regular and continuous (pauses and changes of speed occur only at line-to-line transition), whereas the movement of each digit are irregular and intermittent.

The following diagram contains the superimposed speed graphs of digital movement for a right hand palpating the "right" semi-contour of a plane figure (Fig. 8).

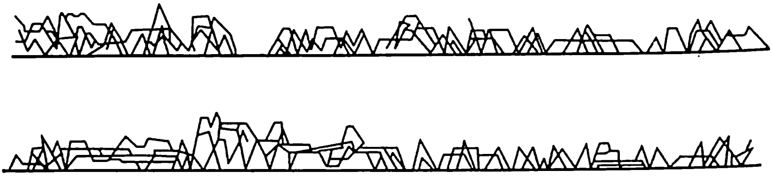


Fig. 8. Speed of right hand digital movement during primary palpation of contour element

Analysis of the graphs reveals that the speed of each digit tends to change constantly, alternately increasing and diminishing. Very often the movement is interrupted by pauses (zero speed).

Further, the moments of speed changes and pauses in the movement of various digits do not coincide in time. Thus, a single movement of the hand along a certain contour line involves a number of partial movements by each digit. The intermittent character of the movement is especially marked in primary palpation of lines of every form and magnitude. Apparently, such intermittency and irregularity in digital movements is obligatory for the analysis of the contour being perceived. If the pauses in manual movement during line-to-line transition provide for the discrimination of two adjoining lines, the intermittency and irregularity of tactile movements along individual lines are required for fractional analysis of the latter. The intervals within individual movements in this case are apparently required for the finest possible fractional discrimination of successively arriving tactile signals.

The discreteness of tactile movements is especially important as regards the measuring function of the hand. Measurement, as we know, is an operation serving to appraise the quantitative relationship between the

measured value and another previously chosen value of the same order adopted as a unit. A line is measured by dividing it into more or less minute sections of equal length. It is clear, therefore, that measuring movements cannot be other than discrete.

Presumably, the partial digital movements comprising the tactile movement of the hand are, in effect, peculiar "sensory units of measurement". Measurement units, however, must be of equal magnitude, whereas the partial digital movements frequently prove to be unequal, often differing rather significantly. The smallest movement may equal 2 mm, and the largest—up to 150 mm, i.e., 75 times bigger. The use of such an unstable measuring unit should, of course, lead to considerable inaccuracy in measurement.

However, the following circumstances should be borne in mind.

1) Large-scale partial movements (exceeding 15-20 mm) are irregular, their speed changing after every 5-50 mm. If we assume the unitary partial movement to be a movement of constant speed and every moment of speed alteration to be the beginning of a new movement, the so-called large-scale partial movements will prove to consist of a number of smaller movements. Such an assumption is quite justified, since the differentiation of movements is based not only on their magnitude, but on their speed as well. Hence, the ratio between maximum and minimum partial movements is reduced to 25:1.

2) As a rule, large-scale partial movements occur only towards the end of the tactile process and in repeated palpation, i.e., when the dimensions of the object are already more or less known and, consequently, its measurement becomes of secondary importance. Inversely, in the initial stage of perception, the partial movements are small (from 2 to 15 mm), i.e., the maximum movements are only 7.5 times greater than the minimum.

3) In the process of palpation, partial movements are performed by each finger; pauses and speed alterations for individual fingers do not coincide in time. Super-imposing the individual graphs of digital movement for the right hand taken during the palpation of one part of the contour, we obtain the picture displayed in Fig. 8. The result is a certain summary movement of all the fingers of a hand. The resultant movement corresponds to reality, since the fingers of the hand move not in isolation, but all together. Judging from the graph, this resultant movement is more fractional than the movement of any individual finger. At the moment when one of the fingers performs a large-scale partial movement, the others make a number of smaller movements. As a result of digital interaction, the values of all partial movements are more or less equalised (the minimum movement proves to equal 4-5 mm, and the maximum—8-10 mm). Apparently the "sensory unit of measurement" roughly represents a mean value derived from the summary partial movements of all fingers.

4) The measurement process performed in contour palpation cannot be regarded simply as a process of applying measurement units to a line. It is far more complex, presenting a series of differentiations of partial digital movements. In addition, the measuring movement is accompanied by consecutive synthesis of the kinaesthetic sensations arising at every partial movement. The conceptual image of the length of the palpated segment emerges as the result of such synthesis. Presumably, the process of quantitative synthesis of "sensory measurement units" takes place not by way of simple summation but in a more complex form.

Apparently, the magnitude of every new partial movement is conditional on the synthesis of the preceding movements. It is no accident, therefore, that the magnitude of partial movements tends to increase towards the end of the tactile process.

The quantitative variation of the "sensory measurement units" in the course of palpation is determined, therefore, by the very process of kinaesthetic analysis and synthesis of measuring movements.

5) The experiments were filmed at a speed of 24 shots per second. Presumably, a greater speed of filming would lead to the discovery of much more fragmentary movements.

All these circumstances allow us to contend that the partial digital movements performed in the process of palpation are "sensory units of measurement", and the corresponding sensations are elementary tactile signals. Such partial movements are the means by which space is divided into quantitative fractions during the process of tactile perception. The kinaesthetic analysis and synthesis of partial movements permit more or less exact reflection of the magnitude of objects.* Linear measurement as effected in the process of manual palpatory movements comprises the successive analysis and synthesis of partial movements.

Palpation, as stated earlier, represents a process of consecutive exploration of the object. Analysis of digital movements performed during the perception of plane figures (contours) reveals the fingers to play an unequal part in such exploration. In bimanual perception, only the middle and index fingers move over the entire contour, maintaining unbroken contact with it. The IV and V digits move mostly in the air. They touch the contour only from time to time. The thumbs and palms of both hands do not participate in the palpation of plane figures.

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* The magnitude of errors in tactile perception depends on the difference between "sensory measurement units" and on the very dynamics of the palpatory process (general speed of hand movement, sequence of partial movements, etc.)

Shot-by-shot analysis of films taken with a speed of 24 shots per second, produces a temporal characteristic of the movements with a precision of 1/24 of a second. Assuming each shot fixating finger-figure contact as a unit, we obtain a quantitative characteristic of the participation of each finger in the tactile process. Every shot displaying a finger in repose on the contour is assumed as a "moment of repose", and each shot picturing digital movement along the contour as a "moment of movement".

Computation of the moments of repose and movement in the palpation of a plane figure gives the following results (Table 1).

Table 1

Correlations between moments of movement and repose for individual digits

Digits	Right hand		Left hand		Palpation
	Movement	Repose	Movement	Repose	
II	249	156	189	228	Primary
	139	101	95	144	Secondary
III	244	116	238	161	Primary
	155	70	126	138	Secondary
IV	111	98	76	105	Primary
	46	29	77	44	Secondary
V	113	81	52	26	Primary
	31	93	0	0	Secondary

Let us assume that moments of movement are accompanied by the simultaneous emergence of both tactile and kinaesthetic sensations (sensations of movement) and moments of repose only by tactile sensations (movement inhibited). Computation of moments of movement and moments of repose brings us to conclude that the tactile image is formed as a result of synthesis of an enormous multitude of tactile and kinaesthetic signals. The total amount of these signals is the greater, the larger and more complex the object of palpation.

In repeated palpation, the overall time of contact (i.e., the quantity of moments of repose and movement) between each digit and the contour is considerably reduced, being

approximately 1.5-2 times less. An exception here is the IV digit of the left hand, which showed 75 moments of movement in primary palpation and 77 in repeated palpation. At the same time the V digit of the same hand had 52 moments of movement in primary and 0 in repeated palpation. Apparently, the load falling on the V digit in primary palpation was transferred during repeated palpation to the IV digit, which accounts for the described exception.

On the whole, the overall amount of tactile and kinaesthetic signals in repeated palpation is reduced. Evidently, the explanation here is that many signals fuse together in accordance with the law of association. This assumption is all the more feasible if we consider that the movements of the hands in repeated palpation are generally more regular and less intermittent. Clear-cut intervals are apparent here only at moments of transition from line to line but are seldom noted when the hand moves along unbroken contour lines.

The observed change in the amount of signals permits us to surmise that primary and repeated palpation are two stages of a single analytico-synthetic process. Primary palpation is concerned with the most fractional analysis of the contour, generating a multitude of tactile and kinaesthetic signals. Thanks to the palpatory movements of the hands these signals are partly (but not wholly!) associated (synthesised). As already stated, the tactile image arising in primary palpation is not sufficiently stable.

In repeated palpation, the associations emerging at the first stage are fixated. At the same time, on the basis of the achieved synthesis, secondary palpation is accompanied by further analysis which is followed by a further, higher stage of synthesis and the formation of an integral and stable image of the object.

Confrontation of the tabulated figures shows that the greatest amount of moments of repose and movement falls on the index fingers of both hands, and a somewhat smaller amount on the III digits. The time of contact between the IV digits and the investigated contour is twice as short on the average as for the index fingers. The minimum amount of moments of repose and movement falls on the V digits (Fig. 9).

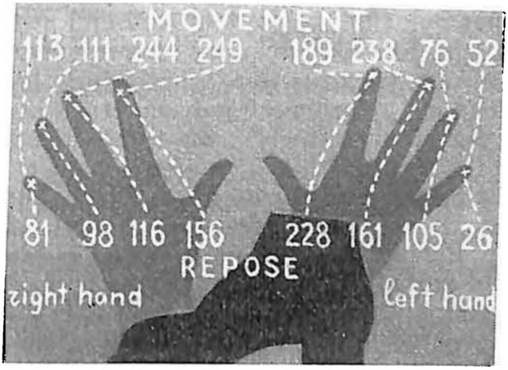


Fig. 9. Time of contour palpation for separate digits ($^1/_{24}$ sec). Drawing shows quantity of moments of movement and repose in primary palpation

Consequently, the share of various digits in the overall amount of tactile signals is different. The bulk of the signals arrives from the II and III digits, whose share is roughly equal. Numerically, these digits are dominant in the process of formation of the tactile image. To obtain a clearer idea of the role of each digit in the palpatory process, let us analyse the cyclogram of their movement. As noted earlier, palpatory movements begin on the

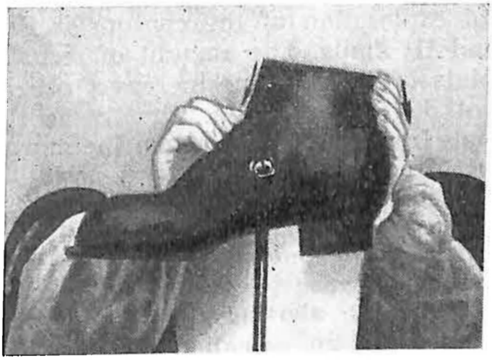


Fig. 10. Position of fingers during hand movement (direction shown by arrows)

extreme upper point of the contour and end at its extreme lower point (the points of manual convergence and divergence lie on one vertical line, the latter beneath the former). The first in order of movement of each hand is the V digit, the second—the IV, the third—the III and the fourth—the II (Fig. 10.).

The V digit moves in front of the other fingers. The II and III digits (last in order of movement) prove to be dominant in the number of tactile signals originating in the process of palpation.

Let us examine the path of the movement of each finger in the order of their sequence (Fig. 11). The V digit performs most of its movements in the air, about the contour, but not along the contour proper. If the tactile image were formed only on the basis of signals from the V digit, it would at best furnish an extremely approximate reflection of the figure's size and only a few of its details (Fig. 12).

The path of the IV digit (the second in order of movement) is close to that of the V (Fig. 13).

Apparently, the IV and V digits play an insignificant part in the formation of the tactile image. Their movements may be regarded only as a kind of reconnaissance of the tactile field, outlining the boundaries of the palpated contour and its details, i.e., as an orienting movement.

The paths of movement of the III and II digits almost completely coincide with the contour of the palpated object (Figs. 14 and 15).

The actual exploration of the contour is thus effected by the II and III digits. The amount of signals reflecting identical points of the contour increases progressively in the course of digital movement. First come the unstable cursory signals from the V digits, then the more stable and frequent ones from the IV digits and last, the "basic" signals from the II and III digits. As a rule, the signals from the IV and V digits are not consciously perceived.

Presumably, the subliminal impulses linked with the digital movements sensitise the motor and cutaneous-mechanical analysers, alerting them for perception.

The dominant role in palpation of plane figures (contours) belongs to the II and III digits which maintain almost unbroken contact with the perceived object. The rest of the digits touch the object only from time to time.

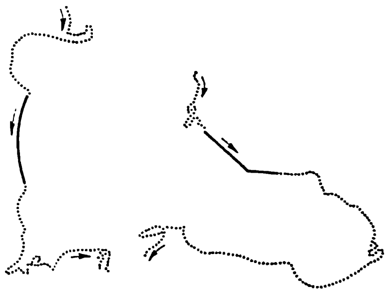


Fig. 11. Path of V digits. Primary palpation. Continuous line shows movement of V digit along contour; dotted line—movement in air

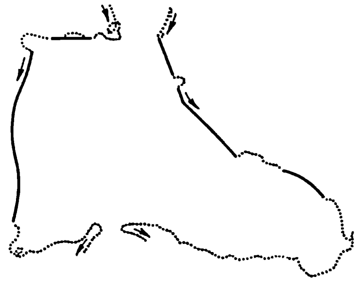


Fig. 12. Path of IV digits. Primary palpation. Symbols as in Fig. 11

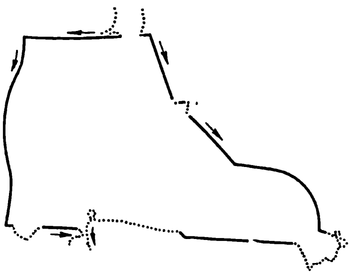


Fig. 13. Path of III digits. Primary palpation. Symbols as in Fig. 11

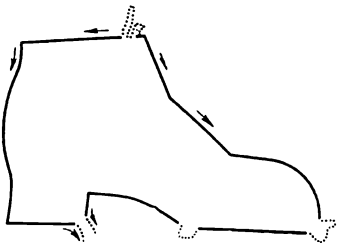
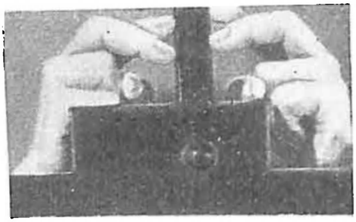
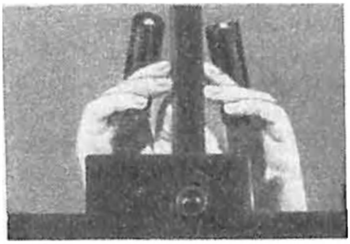


Fig. 14. Path of II digits. Primary palpation. Symbols as in Fig. 11



a



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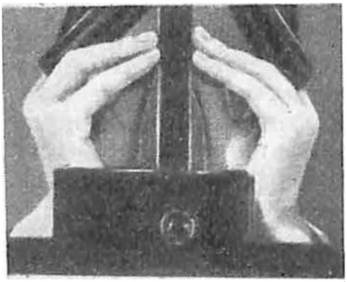

c

Fig. 15. Position of fingers during contour palpation: *a*—in free palpation; *b* - with II digits excluded; *c* - with II and III digits excluded

We must note, further, that the II and III digits always act together.

Thus, every contour detail is palpated twice in the course of manual movement: first by the III digit and then by the II. The reiteration of tactile signals apparent in this case ensures intersignal control. The necessity for such control is all the more important that the tactile signals arriving from different fingers during contact with one and the same contour element, are not wholly identical.

Permanent control of tactile signals is an intrinsic feature of the palpatory process. At each given moment, the middle and index fingers lie on two adjoining areas of the contour. In the following moment the III digit passes on to a new area, while the II occupies the area formerly contacted by the III. Such a combination of succession and simultaneity in the conjoint movement of both fingers apparently furnishes the most favourable conditions for analysis and synthesis of tactile signals.

The dynamics of digital interaction are determined by the distinctive features of the object, primarily the shape of the contour lines. As a rule, straight lines are felt with two digits (II and III); in the case of curves and broken lines, the IV, V and sometimes I digits are involved as well (Fig. 16). Accordingly, at every given moment in the palpation of a straight line, the subject distinguishes two points; in curves and broken lines he discriminates three

and more, which is in full accord with the requirements of geometry.

Particularly interesting from the geometric point of view is the palpation of a complex contour element (Fig. 16). While the four fingers perform relatively synchronous movements along the curve *abc*, the thumb fixates point *d*. Differentiation of the distances between finger-contour contact point altering during movement, permits the curvature of line *abc* to be evaluated with maximum precision, the hand acting like a pair of dividers.

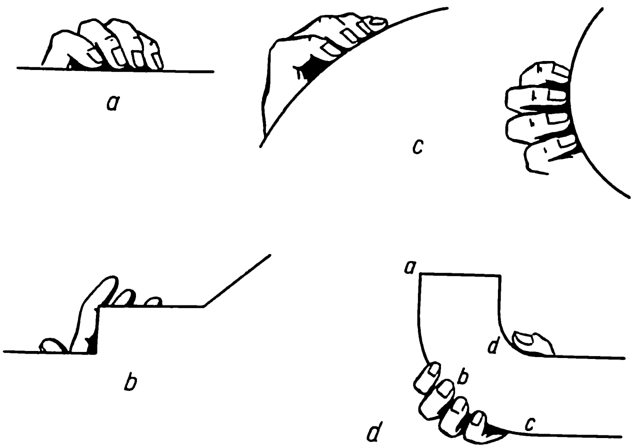

Fig. 16. Position of digits during palpation of contour lines:
a—straight line; *b*—broken line; *c*—curve; *d*—complex contour element

A different picture of manual interaction arises during the bimanual perception of three-dimensional objects.

The thumbs, middle and index fingers are constant participants in this process. Their conjoint (synchronous and asynchronous) movements are required for precise reflection of the relationships between the object's elements in all three dimensions.

Non-participation of the thumbs in the palpation of three-dimensional bodies results in the formation of inadequate images. The palms, too, take an active part in three-dimensional perception, being needed for the perception of surfaces. Exclusion of the palms considerably

protracts the palpatory process and increases the number of return and repetitive movements. The IV and V digits are also more active in the palpation of three-dimensional bodies.

Experiments involving the successive exclusion of various digits and palms show a major role in the perception of three-dimensional bodies to be played by the size of the contact area between the hands and the object. The greater the area, the faster the process of palpation and the more precise the tactile image.

The summary results of cited experimental researches allow us to delineate certain distinctive features apparent in the interaction of cutaneous and kinaesthetic analysers in the process of tactual perception.

In the first place, this interaction proves to be dynamic, the numerical correlation of tactile and motor sensations changing continuously. In the case of broken and curved contour lines the share of tactile signals is larger for straight lines. It is also greater with three-dimensional objects than with plane figures. During the movement of each hand, moments of movement alternate with moments of repose. Hence, tactile sensations are alternately accompanied or unaccompanied by motor sensations.

In bimanual palpation of symmetrical contour elements the moments of movement and repose in both hands are synchronous. With asymmetric elements, they are asynchronous, moments of movement in one hand corresponding to moments of repose in the other. Hence, the relationship between the two sides of the tactile and kinaesthetic analyser changes also.

In the final issue, the dynamics of interaction between these analysers is determined by the spatial features of the object perceived. In the process of palpation, the amount of tactile signals alternately grows and diminishes,* but their overall inflow is never interrupted. The flow of kinaesthetic signals, conversely, is intermittent, sensations of movement alternating with sensations of repose.

Owing to that, the united activity of the tactile and kinaesthetic analysers ensures both fractional perception of the perceived contour and the reflection of its continuity.

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* Presumably, the quality of such signals also constantly alters together with the values of pressure and friction.

7. CONDITIONS REQUIRED FOR THE FORMATION OF AN INTEGRAL IMAGE IN BIMANUAL PALPATION

In the process of bimanual perception each hand palpates one side of the object. As noted elsewhere, the spheres of manual action are sharply divided. Hence, an integral image of the object may arise only from synthesis of tactile signals from the right and left sides of the object.

One of the major requisites for such synthesis in usual perceptual conditions is the division of the manual functions, i.e., functional asymmetry.

It is logical to ask how will bimanual perception proceed if both hands are placed in equal positions, without dividing their functions. Such a question was first raised by Ananyev and Davydova in an earlier cited work (§ 4).

Subsequent investigations in this field conducted by ourselves and Idelson, confirmed and modified the facts discovered by these authors. First of all, we disclosed that synchronous movements during bimanual palpation of symmetric figures do not result in a splitting of the integral tactile image. Certain distortions arising in this case relate, chiefly, to the amount and shape of individual contour elements. Occasionally, the subjects omit or, inversely, add certain elements in their drawings, the right and left sides of the contour being distorted equally.

The cause of these distortions is as follows. In the process of synchronous palpation (according to the experimenter's instructions) the simultaneous pauses of both hands at the points of transition from one symmetric line to another are considerably reduced. This, in turn, causes difficulties in the discrimination of successively arriving tactile signals.

In the synchronous palpation of asymmetric figures, the situation is reversed. The equalisation of manual functions causes difficulties in the elaboration of an integral image. In synchronous palpation of asymmetric plane figures, from 7 to 15 repeated palpations are required to overcome the duplicity of the subjective image.

As evident from our findings, it is almost impossible to achieve total synchronism in the movements of hands palpating asymmetric contours. Contrary to instructions, the subject involuntarily stops moving one or the other hand. It stands to reason that with complete synchronism the formation of an integral image would require not 7-15, but a much greater amount of repeated palpations. In the

process of synchronous palpation the image of an asymmetric contour forms slowly and gradually, each new phase not only supplementing its predecessor, but to a certain extent negating it, essentially modifying the picture.

As seen from the picture series applied, the formation of an image begins with the determination of the point of manual divergence and subsequently convergence, i.e., the points where the hands come into direct contact. In this way the connections between signals from each hand are closed, establishing the figure's basic coordinates, around which the remaining elements are grouped in the course of subsequent palpations.

The determinative influence of these points on the entire process of bimanual perception is evident from specially staged experiments in which subjects were asked to feel one and the same figure each time placed in a new position, viz., turned to 90°. In every successive position the figure was believed to be new, i.e., was not recognised by the subject.

The image arising in synchronous bimanual palpation is extremely unstable. With every change in the figure's position it is formed anew. Hence, the entire system of relationships between the two sides of the tactile analyser is readjusted, and the tactile signals from the right and left hands are associated in a new way. With every new change in the figure's position in relation to the subject, the formation of its image is begun by determining the points of manual convergence and divergence. It is interesting to note that synchronous perception always begins with palpation of the object's left side which serves as reference for analysis of the object as a whole. This and earlier cited facts testify to the overall dominance of the left side of the tactile analyser.

The formation of the tactile image of an asymmetric object by synchronous movement of the hands is accompanied by multitudinous distortions, particularly often by the fusion of closely localised contour elements (Fig. 17).

As mentioned earlier, a major precondition for the differentiation of successively arriving tactile signals are pauses between individual palpatory movements. These pauses are considerably reduced during synchronous palpation, which hampers the discrimination of tactile signals.

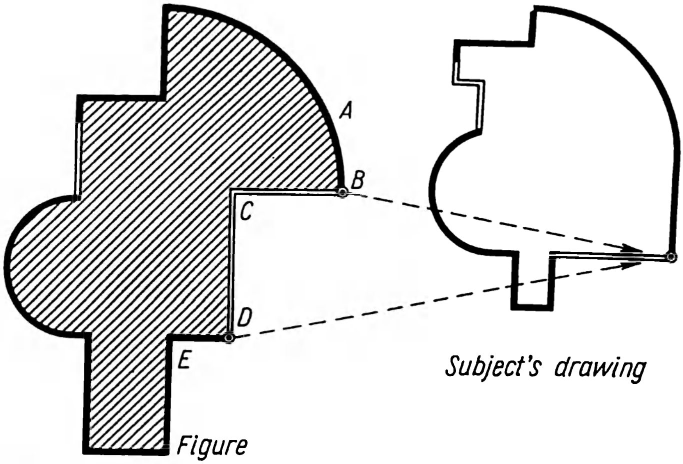

Fig. 17. Fusion of closely adjacent contour elements during synchronous palpation
Subject could not discriminate angles *ABC* and *CDE*, which were fused into one angle in the tactile image

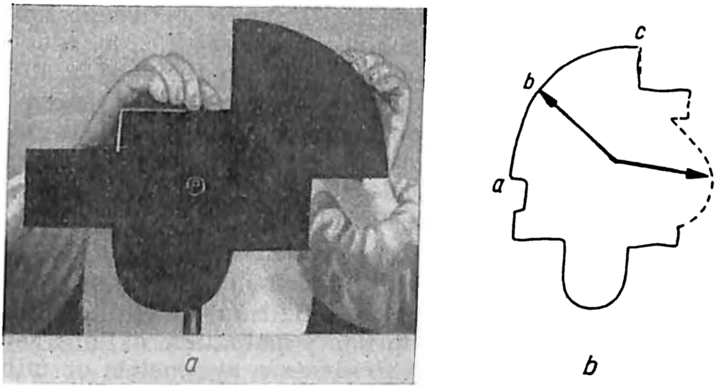

Fig. 18. "Mirror duplication" of contour elements in synchronous palpation:
a—figure; *b*—subject's drawing

Another typical distortion consists in the transfer of contour elements from one side to the other, i.e., "mirror duplicity" of elements (Fig. 18).

In the depicted figure, curve *abc* occurs only on the right side, yet the subject drew it on the right and left. Such

transfer occurs only in synchronous, but not in asynchronous movements of the hands, being occasioned, apparently, by irradiation of excitation between symmetric points in the two hemispheres and the transfer of conditioned reflexes from one side of the analyser to the other.

Precise discrimination of signals from the "right" and "left" sides of an asymmetric object is possible only when moments of repose and movement succeed one another in each hand without coinciding in the two extremities.

By and large, synchronous perception of three-dimensional bodies is similar to synchronous contour perception. The community between the two consists in the relatively swift and easy perception of objects and comparatively difficult elaboration of images for asymmetric figures. But they also reveal distinctions, viz., the synchronous perception of three-dimensional objects is several times easier than that of contours. Whereas synchronous contour palpation was followed by image splitting in 60 per cent of cases, the percentage for three-dimensional bodies was only 10. The speed of palpation for three-dimensional figures is about three times higher than for plane objects.

These facts are explained by the more active participation of the cutaneous-mechanical analyser, i.e., by a considerably larger share of tactile signals in the case of three-dimensional bodies. The increase in the contact area between the hand and the object creates more favourable conditions for the synthesis of tactile signals.

However, in synchronous palpation of three-dimensional bodies there is more marked transfer of image elements from one side to the other. The direction of transfer is from right to left and vice versa, the elements of the structurally more complex side usually being transferred most often. For this reason, after primary palpation of an asymmetric figure, the subject produces a symmetric or mirror drawing (Fig. 19).

It is interesting to note that in cases when the subject knows or is warned about the possibility of transfer, it either does not occur at all, or is considerablly less marked. This, apparently, is a manifestation of the inhibitory influence of the second signal system on the irradiation of nervous processes in the analyser.

Thus, the process of image formation in the bimanual palpation of asymmetric figures is contradictory. The con-

tradictions are occasioned by conflict between the right and left side of the tactile analyser. With synchronous hand movements, two foci of excitation arise simultaneously in the cortex, each corresponding to either side of the tactile analyser (localised in the right and left hemispheres). Conflict between these foci leads to the splitting of the tactile image.

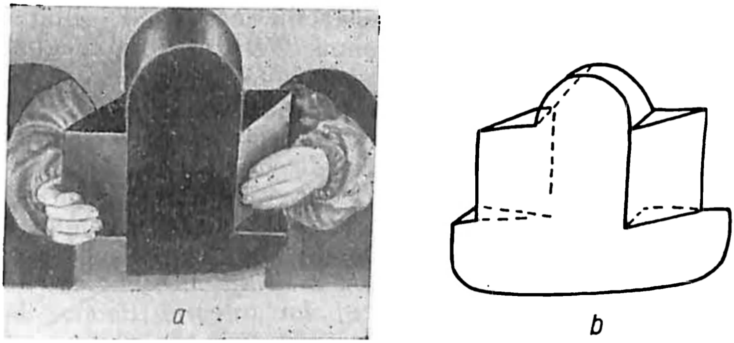

Fig. 19. Distorted image of three-dimensional figure in synchronous palpation:
a—figure; *b*—subject's drawing

Apparently, synchronous bimanual perception gives rise to approximately the same picture as evident in binocular viewing of two objects (when one object is viewed by one eye and the other by the other) (12). In synchronous palpation of symmetric figures, the images obtained from the right and left hands are similar: viz., there is no prolonged conflict of excitatory foci, which are rapidly integrated.

In the case of asymmetric figures, i.e., when simultaneous tactile signals differ, the conflict of excitatory foci is more prolonged. Only after multiple repeated palpations the conflicting foci are finally integrated, the split is overcome and an integral tactile image is formed.

The cited experimental data testify that the two sides of the tactile analyser stand in complex relationships. The dynamics of their interaction are marked by continuous phasic alternation of induction and irradiation. When palpating symmetric objects, the sides of the tactile analyser act as functionally equal units, whereas in case of asymmetric objects they are unequal.

The summary experimental findings quoted in this and preceding paragraphs allow us to define the basic condition for synthesis of tactile signals from twin receptors, i.e., for the formation of an integral image.

With total (mirror) similarity between simultaneous tactile signals, the objects concerned are perceived as symmetric. With considerably differing simultaneous signals, the image becomes split. The splitting of asymmetric figures is avoided only if the bimanual tactile movements differ in their phases, i.e., are asynchronous. Whereas the adequate synthesis of a pair of visual signals requires a moderate spatial disparity between the relevant stimuli, *the major requisite for a pair of tactile signals (in the perception of asymmetric figures) is temporal disparity. This latter, i.e., a phase difference between palpatory movements (non-coincidence in the sequence of moments of movement and repose for each hand) is actually the basic condition for the synthesis of tactile signals from the object's right and left sides, i.e., for the formation of an integral image.* The aforesaid phasic difference accounts for the non-coincidence of excitation and inhibition in the hemispheres, the continuous alternation of moments of irradiation and induction.

8. SYNCHRONOUS BIMANUAL PALPATION OF TWO OBJECTS

As subjects invariably state in their verbal accounts, they find it very hard to distribute their attention between the left and right sides of objects during the synchronous bimanual perception of symmetric bodies. Earlier we have shown that these difficulties are explained by conflict between tactile signals.

It was natural to suppose that such conflict would be still more manifest in the synchronous palpation of two objects.

Relevant experiments, however, unexpectedly refuted this assumption. Under definite conditions, synchronous palpation of two objects was shown to be fraught with less difficulties than the perception of one object.

The investigation consisted in the following. The blindfolded subject was asked to feel two objects secured to a holder. The resulting images were recorded in drawings and verbal accounts. Palpation (consecutive exploration) was performed with a) all fingers of both hands, b) index fingers; c) index fingers and thumbs.

The scope and distinctive features of two-figure reflection turned out to be dependent on the degree of similarity between the figures and their mutual position in the tactile field.

Similar contours localised symmetrically in regard to a vertical axis were perceived with the greatest ease in all three cases, which stands in analogy with the perception of a single symmetrical figure.

In the synchronous perception of two asymmetric figures, the situation is different. If they are felt with the index fingers only, the subject does not form integral images, but retains only isolated details (Fig. 20). The perceptual dif-

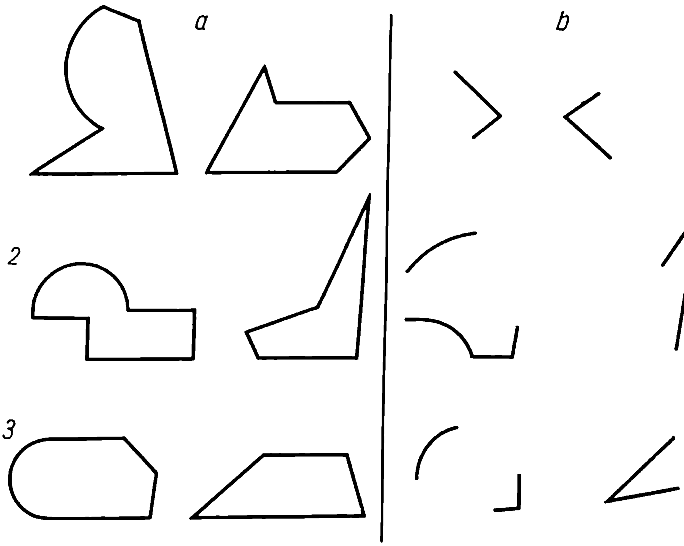

Fig. 20. Figures and subject's drawings after synchronous palpation with index fingers alone:
a—figure (1, 2 and 3); *b*—drawings

ficulties in this case are evident from the subjects' verbal accounts. Highly similar or symmetrically arranged figures, or sharply distinguished elements of two figures are reflected with relative adequacy. The tactile perception of two figures involves two tasks: 1) assessment of the mutual position of contour elements within each figure and 2) as-

sessment of the mutual position of the two figures proper. The two tasks cannot be fulfilled by the index fingers alone; if it is partly possible to discriminate simultaneously palpated elements in both figures, consecutively palpated elements within each figure cannot be discriminated at all. In addition, synthesis of signals consecutively arriving from the same figure becomes difficult. For this reason, relationships between individual lines in different contours may to a certain degree be reflected, but line-to-line relationships within each contour may not.

The picture changes sharply when the index fingers are aided by the thumbs. In this case relationships between the elements within figures and between the figures proper are usually reflected adequately (Fig. 21).

The supportive function of the thumbs is especially obvious in these experiments. As a rule, they remain almost immobile throughout the tests, strictly fixating the points of reference, to which all other contour elements in the figures are referred. It is exclusively owing to such fixation of reference points that consecutively arriving tactile signals from both figures can be analysed and synthesised. Interaction between the thumbs and index fingers ensures the adequate reflection of interelemental relationships in each figure and relationships between the figures proper. Some subjects were asked to palpate the figures with all ten digits simultaneously. This also involved certain difficulties. Very often, the subjects could perceive separate elements, but could not form integral images.

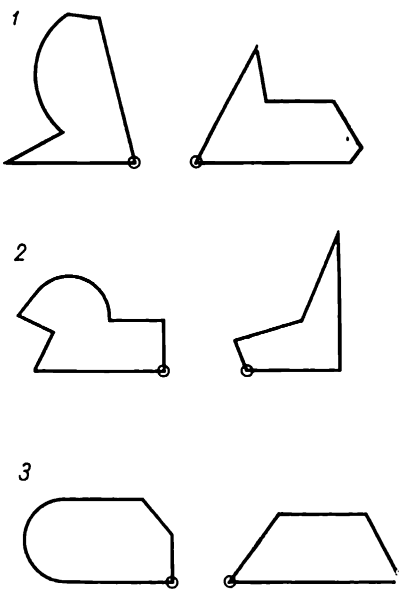

Fig. 21. Drawings of figures after synchronous palpation with II and I digits.
Drawings of figures shown in Fig. 20. Circles show position of thumbs

The use of all ten digits in palpating two plane figures gave an increased amount of tactile signals, which complicated their analysis and, hence, synthesis as well.

The adequate reflection of two plane figures perceived by synchronous palpation, apparently requires the inflow of a certain minimum of tactile signals. This minimum is ensured by means of interaction between the index fingers and thumbs. The index fingers alone cannot provide a sufficient inflow of signals, whereas with all ten digits active, the supply is superfluous. This, however, refers only to plane figures, three-dimensional objects normally requiring the participation of all ten digits.

The synchronous palpation of one and two figures reveals both similarities and distinctions. A common feature of both processes is that the elements of one figure (case I) or two figures (case II) arranged symmetrically in regard to the vertical axis of the tactile field are perceived faster and more precisely than asymmetric elements.

The distinction between the two processes lies in the fact that adequate images of two figures (case II) are formed faster (as a rule, after two or even one palpations) than the image of a single figure (case I). As already stated, in similar conditions, the image of a single figure is formed only after 7 to 15 repeated palpations.

The synchronous bimanual palpation of a single figure produces a "split" image and involves side-to-side transfer of individual elements, which is an evidence of intersignal conflict. With two figures, such occurrences are absent, the only apparent defects being distorted proportions and spatial relationships, or omission of individual elements.

The verbal accounts of experimental subjects likewise testify to the greater facility of two-figure perception as compared with palpation of single figures.

These findings permit us to conclude that intersignal conflict is typical only for synchronous bimanual perception of one figure.

How, then, are we to explain the greater comparative facility of bimanual two-figure perception?

As stated elsewhere, the bimanual tactile field is sharply demarcated into two parts by the vertical axis, a phenomenon associated with the functional asymmetry of the hands. It is this circumstance that accounts for difficulties in the analysis and synthesis of the "right" and "left" side

of a single object and in the formation of its integral image. On the other hand, the same circumstance facilitates the analysis and synthesis of signals from two objects. The fact that the bimanual field is divided into two parts makes it possible to discriminate two simultaneously perceived objects with a sufficient degree of precision. Under such conditions the interacting digits of each hand act as a coordinate system serving to reflect one of the two objects, whereas the interacting hands function as a coordinate system reflecting interobject relationships.

Here we have an obvious manifestation of the close connection (subordination) between the bimanual and monomanual haptic systems.

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Analysis of the presented experimental data shows the extreme plasticity of the mechanisms of bimanual perception.

The interaction between the sides of the bireceptor tactile analyser is mobile, being adjusted in different ways depending on the conditions and the object of perception.

Taken in the aggregate, the cited experimental data clearly demonstrate the following cardinal feature of bimanual perception. The characteristics (spatial and temporal) of palpatory movements of both hands depend on whether the perceived object is localised symmetrically or asymmetrically in respect to the vertical axis of the tactile field. When palpating a symmetric figure or the symmetric elements within a figure, or two symmetrically localised figures, the manual movements are synchronous, while in the case of asymmetric figures or elements they are not. The alternation of synchronous and asynchronous conjoint bimanual movements in the perception of complex-shaped objects ensures their adequate reflection.

When palpating an object, the interacting hands (and digits) perform a multitude of various movements, including consecutive contour exploration (basic), adaptive excursions (digital micromovements), return and repetitive movements, etc. This originates a multitude of tactile signals, not all of which, however, are included in the integral image of the object. The perceptual process proper incorporates elements of control and selection, and, consequently, elementary, i.e., sensory generalisation of tactile signals.

Bimanual tactile perception is vital for the development of man's knowledge about space. Providing a means for the sensory discrimination and comparison of the size, shape and position of perceived objects, it plays an important role in the formation of geometrical concepts.

Apparently, it is the experience of bimanual tactile perception that gives origin to the multitudinous conceptions underlying the notions of symmetry, similarity, etc.

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ON THE BASIC PROPERTIES OF THE MENTAL IMAGE AND A GENERAL APPROACH TO THEIR ANALOGUE SIMULATION

By L. M. WEKKER

The criterion of the depth of understanding and insight into the fundaments and aspects of a phenomenon investigated by science is the ability to reproduce it, if not in a technically realised, at least in a mental model. That is precisely why for materialist psychophysiology, from Descartes and La Mettrie to Sechenov and Pavlov, the technically realised or ideal machine model of the nervous system served as an epistemological standard of knowability and a means of scientifically proving the deducibility of the mental functions from the laws governing the functioning of the material apparatus whose property they are.

However, modern cybernetic synthesis has put the application of the method of analogues on a fundamentally new level. Having generalised the theoretical premises of psychophysiology and the reflex theory cybernetics revealed the general principles of control and the laws of data processing in living organisms and technical devices. Analogues of neuropsychic functions in modern automated production, and the processes operating within the analogue systems themselves turned out to be basically subordinate to the same laws governing control and communication. For the first time it became possible to embrace simulated and simulating phenomena with general structural and functional principles and a single apparatus.

General Historical and Theoretical Premises for Stating the Problem of the Image

The first basic step in developing the theory of the image was the realisation of the fact that, although the structure of the image reproduces the properties of the object and

masks processes in the substrate, the image remains the property of its bearer and is formed in the course of the latter's activity (Aristotle).

This necessarily posed the problem of deducing the characteristics of the image from the mechanism of the performance of its material apparatus. But the solution of this problem could not, essentially, have been constructively started until the general laws governing the functioning of the nervous system, which is the bearer of the image as an elementary mental phenomenon, were revealed.

That is why materialist psychophysiology begins with Descartes, who discovered the general reflex principle of the functioning of the nervous system. Descartes, however, did not extend the reflex principle to the mental sphere, largely because of the obscure nature of the relation between the object structure of the mental and the processes in its substrate.

Then came a stage in the development of the reflex theory filled with sharp ideological collisions connected with the struggle between materialist neurophysiology and idealist psychology. The obstacle to an adequate generalisation of the reflex theory was the neurophysiologic trend which endeavoured to explain the mental mechanisms in accordance with the relations between a function and its organ "common" to somatic acts, i.e., to deduce the object structure of the image directly from the "black box" of intracerebral processes. Since this cannot be done, the positions of idealist psychology long remained quite strong. A way out of this blind alley was opened by Sechenov's conception of the reflex. Starting with an analysis of the structure of behaviour acts Sechenov demonstrated the inadmissibility of isolating the central intracerebral links of the reflex act from the initial and final interaction with the source of the organism's reactions, and thereby showed the groundlessness of the attempts to deduce the object structure of mental processes directly from the intracerebral nervous dynamics. The functional scheme of the mechanism of mental acts (particularly and primarily perception) interlocked with the object whose properties are reflected in the image.

However, the three basic propositions of Sechenov's conception, namely, regarding the reflex mechanism of mental processes, the inadmissibility of severing the mental

components of the reflex from its initial and final links, and the control functions of these components in the organisation of response reactions, cannot be correlated within the framework of the old, essentially still Cartesian, scheme of the reflex arc. That is why the question of the character of the relations between mental processes and the different links of the reflex act, the specific character of the reflex effects which form mental, particularly sensory processes, compared with the effects of motor or other executive acts, has actually remained open. That is precisely why the conception of the cerebral component of the reflex as the last link in the mechanism of forming the image, and as the only and final substrate of this image, persisted and is still widely accepted. The next stage in the search for a concrete functional scheme of the reflex mechanism of the image is connected with the experimental facts and theoretical propositions of I. P. Pavlov. Pavlov analysed the dynamics of sensual images in different neuropsychic disturbances and arrived at the conclusion that there was much in common in the behaviour of sensory processes and the dynamics of reflex effects (such as motor, secretory, etc.). If sensory processes behave like reflex effects, i.e., are governed by the laws of the dynamics of the latter, there are reasons to believe that the image, from the point of view of the correlation of its mechanism with the different links of the reflex, is realised precisely by the effector link of the latter.

These conclusions are suggested by the data of numerous subsequent experimental studies pertaining to different characteristics of the work of analysers. Thus various studies have very definitely demonstrated that the action of a weak supplementary stimulus lowers the thresholds of the analysers, whereas the action, of a strong stimulus, on the contrary, raises them (Lazarev, Kravkov, Teplov, Kekcheyev, Schwarz et al). The Pavlov-established general law of change in the value of the reflex effect under the action of a supplementary stimulus manifests itself with regard to sensitivity also in this case. But the reflex change in the thresholds of the analysers can hardly by directly determined by the dynamics of the *executive* effector organs proper. It is therefore natural to associate the reflex mechanism of sensory acts with the effects of intra-analyser reflexes. In such cases there may be classic (but

auxiliary with regard to the sensory function of the analyser) motor reflex effects of its propriomuscular apparatus, as well as efferent effector changes in the receptor organs themselves. Today we have proof of various forms of influence of the centre of the analysers on their receptor periphery (Greenstein, Granit, Sokolov). Thus an analyser is a feedback system which may be either positive (sensitisation) or negative (adaptation). All this indicates an essential connection of the image-building mechanism with the effector links of the intra-analyser reflex acts. However, all these data still say little about the specific characteristics of the reflex effects which form the object structure of perception.

In modern psychology attempts are being made to approach the theory of perception from the standpoint of simulation problems (Rozenblat, Selfridge, Deutsch, Hebb, George). However, most of the suggested analogues essentially reproduce a functional scheme *not of perception proper, but of the act of recognition*, i.e., in them the sensory problem of image-building is translated into the logical language of the operation of referring the perceived image to a definite class. The mechanism of formation of specific structural characteristics of the image and the influence of these characteristics on the organisation of the behaviour act remain unrevealed.

To lock the ends of the physiological study of reflex mechanisms of image-building with the psychological study of its object structure, it is necessary to correlate the concepts of "nervous process", "reflex effect", and "perceptual image" (as a *mental* reality) in a single and sufficiently general theoretical system.

Each of these three concepts forms the basis of the scientific field which corresponds to its object. The concept of the nervous process is the point of departure for neurophysiology, the concept of the reflex and the reflex effect is the point of departure for the reflex theory. That is why the content of these concepts can be revealed only by going beyond the limits of neurophysiology and the reflex theory, just as the structure of elementary mental formations cannot be revealed by the internal means of the psychological system of concepts as such. The nervous process and the sensation or perception which arises on its basis are correlated as different *signal components* of

the reflex act. In their turn these components are connected with the terminal effector links of the reflex by relations of regulation or control. That is why these concepts may be adequately correlated, and their specific differences revealed on the basis of general principles, only by means of a general theory of control and information whose signals effect this control.

CONCERNING CYBERNETIC PRINCIPLES OF THE THEORY OF IMAGE

Today there are essentially two different trends in the interpretation of the concept of "information". The first of these trends originates from the theory of communication. Its main significance and value are in the creation of principles of measuring informational phenomena. The existence of measuring methods considerably extends the possibilities of investigating sensory processes and opens ways of determining the handling capacity of analysers, eliminating noise in their work, developing optimum coding methods, etc. However, this trend is purely formal. Here the concept of information is in the end identified with the concept of "amount of information". From this point of view the essence of information as a statistical process receives its exhaustive expression in the number of corresponding units of measurement it contains. The fundamental essential and not only formal interrelation between information and physical entropy is not utilised to reveal the structural characteristics of information. Together with the question of the structural characteristics of information, the question of the structure of the sensory image as a signal, as distinct from the nervous process on whose basis this image arises, also turns out to be outside the sphere of consideration. The second approach to the concept of information is of a general cybernetic nature. It treats information as a factor of control and, accordingly, as a definite organisation of processes circulating and operating in the control circuit. It is no accident that the foundations of this approach were laid down by Norbert Wiener who points out that the "signals are themselves form, pattern and *organisation*" (my italics—*L. V.*).*

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* N. Wiener, *Cybernetics and Society*, Foreign Literature Publishers, Moscow, 1958, p. 34.

In accordance with such a general approach to the nature of information, which arises from the essence of the cybernetic synthesis of the communication theory and the control theory information may be defined as the retention and reproduction in its bearer of the ordering of the states of the source. It is precisely this spatio-temporal ordering of the states of the bearer commensurate with the source that makes it possible to utilise the latter as a regulator of behaviour, i.e., to bring the executive reactions of the control system in conformity with the peculiarities of the source of information. It is the transfer of this conformable ordering to the functions of the effector organs of the system that realises the control process, of which the information is a factor.

The information working in a control system always exists as signals which are its structural units and are embodied in certain states of its material bearer (e.g., vibrations of sound, impulses of nervous excitation, or deformation stresses in muscle receptors). A signal is a set of states ordered in a certain manner. The relation of the signal ordering to the source ordering is a relation of two sets of elements (for example, the relation of a set of values of receptor potentials to a set of values of stimulus intensity). Since a signal is a set of states of its bearer, ordered commensurate with the source, the general principles of ordering of the states forming the signal may be examined from the standpoint of the theory of mapping of sets. The most general form of relations between the image-set and the pre-image-set (in the mathematical, not psychological, sense of the term) is homomorphism. The homomorphous relation of sets is determined by the presence of a simple correspondence of both sets and the relations between these elements. In the particular case, when this simple correspondence is mutual, homomorphism is transformed into isomorphism which determines and even exhausts the semantic content of the concept of information. Two sets are thus isomorphous if their elements in pairs, are in mutual one-value correspondence ($x \in X \rightarrow y \in Y$, $y \in Y \rightarrow x \in X$) and the functions which express the relation between elements in one set are in mutually one-value correspondence to the functions which express the relation between elements in the other set

$$x_2 = f(x_1) \rightarrow y_2 = F(y_1),\ y_2 = F(Y_1) \rightarrow X_2 = f(X_1).$$

The isomorphous relation between the set of states of the bearer of information to the source-set determines the general form of mutual ordering of these two sets which makes the signal a code of the source of information. Coding modulates the information bearer's own states in accordance with the ordering of its source and transfers this ordering to the physical alphabet of the bearer (communication channel or control circuit). In the event of the absence of noises, which destroy, in the isomorphous source, the ordering of the bearer's states, the entire amount of information, or the entropy of the source, is reproduced in the signal.

As can be seen from the conditions of isomorphism, which determines the orderliness of the code signal, here we have a correspondence of elements of two sets and functions which express the relation between them, but we do not have the characteristic of these elements, and the specific character of the functions which express the relation between the elements in each of the sets is not fixed. However, a change in the specific form of these functions, while their simple correspondence to the functions of the second set is preserved, *does not disturb the relations of isomorphism*. Thus a set of elements ordered in time may be transformed into a set ordered in space, at the same time preserving the isomorphism of the relations.

Because of the non-fixation of specific characteristics of the set elements and the relations between them the signal becomes a code of all the sets to which it is isomorphous. A code signal with the same amount of information may thus correspond to *various sources isomorphous to it*. But such a relationship of the signal code to the source of information is at variance with the realisation of the control function of the signal. The process of control requires that the functions of the executive organs should be commensurate *precisely with the given source*, in its concrete specificity which distinguishes it from other objects isomorphous to it. Thus it follows from the most general principles of signal organisation that, in order to eliminate unequivocality in the relations to the source and to return from the code to that individual representative of all sets isomorphous to the signal which constitutes precisely the given object of action, it is necessary to decode the information. This decoding may

be carried out by the provision of executive units in the system (as is, in point of fact, done in modern engineering automatic control systems). But in principle it may also be effected in the structure of the signal itself.

Since the conditions of isomorphism require but a simple correspondence of the elements to the functions which connect them in both correlated sets and admit any concrete character of these elements and their relations, these general conditions also include the variant in which the elements and their relations in both sets not only simply correspond to each other, but also reproduce their concrete character [function $y_2=F(y_1)$ coincides with function $x_2=f(x_1)$ and the characteristics of elements x_1, $x_2 \ldots x_n$ coincide with the characteristics of elements y_1, $y_2 \ldots y_n$].

In the variant of set mapping, which occurs with regard to the signal and the source of information, the methods of ordering of the set elements have to do primarily with their spatio-temporal structure. A special case of a code signal in which the modal characteristics of the source set elements and of the forms of their spatio-temporal ordering are retained is an *image* in the true sense of the word (since the corresponding modal and spatio-temporal characteristics of the object are copied here). Thus a two-dimensional spatial set of states of illumination of a TV frame drawn out into a one-dimensional series remains isomorphous to the object and thereby remains its code. But in view of the change in the spatial ordering of the elements it ceases to be an image. A question naturally arises concerning the various forms of mapping in which certain properties of the spatio-temporal structure of sets remain invariant with respect to the transformations which realise this mapping. The necessity of elucidating this question is here dictated by the need for revealing the "scale" of levels of signal organisation on which nervous process may be compared with the image of perception as a "mental reality" arising on its basis.

The transformations with respect to which the one-dimensional series as a general structural property of space and time remains invariant are the most general form of such preserving mappings.

If additional conditions of preserving not only one-dimensionality, but also unindirectionality of a series of

elements are superposed on this general form of transformations of the spatio-temporal ordering of the sets, it is possible to produce transformations which preserve the temporal characteristics invariant. These transformations lead to representation of the temporal ordering of the proto-image-set in the image-set. If another additional condition consisting in preservation of mutual spatial continuity is superposed on the most general mutually single-valued spatio-temporal transformations, it will lead to a type of set mapping which preserves as invariant or represents the topological properties of the spatial ordering. The topological transformations, being a special form of a mapping of the *spatio-temporal* ordering, are at the same time a mapping of the most general properties of *spatial* continuity. If, furthermore, one more additional limitation—the condition of collinearity (i.e., preservation of corresponding points in one straight line)—is superposed on the transformations which effect the mapping, this will lead to the next, more specific group of projective mappings in which straight lines are transformed into straight lines. However, the parallelism of lines does not remain invariant in the general form of projective mappings. For here it is not represented, but is coded by a certain magnitude of the angle of convergence. Such representation of the relations of parallelism is achieved in the next, still more specific, group of transformations which effect affined mapping.

Transformations of similarity, the specific character of which transformations, compared with the general form of affined mappings, being that in addition to all the invariants of the preceding groups they also preserve the magnitudes of the angles, are a special form of affined transformations. The spatial form of the proto-image is preserved together with the parallelism of the lines and the magnitude of the angles. Since form embodies the integral structure of the object its reproduction leads to an *image* not only in the scientific sense of this term, but also in its conventional sense. However, this form of mapping produces an image of the shape of the object, subjecting its metric relationships or dimensions to scale transformations. And only the next, still more specific group of mappings effected by metric transformations, leaves invariant the entire aggregate of spatial properties

of the mapped set. The spatial structure of the proto-image object is reproduced here with such completeness that the image and proto-image become congruent, i.e., they coincide when superposed. The fact of coincidence upon superposing vividly embodies the copying of all the characteristics of the spatial structure of the proto-image object.

Thus an analysis of the possible method of organising a set of signal elements relative to the source, made from the point of view of the principles of set mapping, shows, first, that an image is a special case of code signal and, secondly, that there is a hierarchic series of representations of different levels of community, the most special and most complete of which is *representation as a metric invariant.*

The obtained hierarchic series of forms of spatio-temporal organisation of signal sets (from the code form, which satisfies only the general conditions of isomorphism, to representation as a metric invariant) yields the sought-for *scale or spectrum of structures of information processes in which further analysis may compare sensations and perceptions with the nervous processes on whose basis they arise*. For, if perception is a mental reality (Sechenov), as distinct from a nervous process as a neurophysiologic reality, then, for this difference to be really substantiated, it must be backed by specific relationships of the methods of organisation of the two compared phenomena.

The material of modern neurophysiology and experimental psychology makes it possible to refer the forms of organisation of nervous processes in the analyser and the image of perception arising on their basis to different levels of the aforesaid scale.

Whereas the transformation of a physical stimulation into a physiological process of nervous excitation upon entering the analyser was formerly appraised primarily as a process of power transformations, today it is quite clear that the essence of these transformations in the receptor lies in the reception and transformation of information. Numerous subtle electrophysiologic and other studies (Granit, Gray, Gershuni, Nuberg, Byzov) show that the receptor apparatus is an encoding device, while the excitation spreading from the receptor is by the very essence of its characteristics and laws a nervous code of the acting stimulus.

Since the volleys of discrete excitation spreading from the receptors are governed by the "all or none" law, they cannot be modulated in amplitude or phase and the nervous process circulating in the analyser path is a frequency-pulse code. The indiscrete gradual excitation arising in the receptors and analyser centres may be treated as continuous codes with amplitude modulation. Thus there are experimental grounds for regarding the nervous process, on the basis of which images of perception are formed, as a general code form of information signals.

On the other hand, in addition to the data on objectness, integrity and constancy of perception which clearly express the invariant structure of the image precisely as a representation, experimental psychology has recently obtained still more concrete data of the Akishige school,* which show that the constant image is a metric invariant.

The perception image and the nervous process in the analyser turn out to be incorporated into the single series of hierarchically coordinated forms of organisation of information processes. But inside this community there are differences expressed in their belonging to different levels of this spectrum of forms. The nervous process belongs to the most general form of signal codes, while the constant perception image occupies the opposite extreme, being the most specific and at the same time the most complete form of representation whose structure is congruent to the object.

However, for a final solution of the problem of the method of organisation of perception as a signal in its relation to the nervous process it is necessary to make a further comparison of both these interrelated phenomena on the basis of a general objective method of analysis. Such a strictly objective comparison may be effected by revealing the control function of both types of signals with regard to their common effector output of the control system, i.e., to the dynamics of the executive organs.

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* Akishige, *Experimental Research in the Structure of Perceptual Space*, Kyushu University, Fukuoka, Japan, 1961.

The regulatory influence of the image on the organisation of the executive output of the organism's reflex control system manifests itself objectively in the methods of assignment and realisation of programmes of motor effector acts. The programme of a motor act may either be assigned by the structure of the working organs and internal connections of the system, or may be a passive result of blind trials and errors, i.e., of a sorting out of fortuitous reactions of the system, or, lastly, it must be determined by the method of ordering of the control signals.

A characteristic feature of the structure of the effectors of skeletal muscles, as the main mentally controlled executive organs, which sharply distinguishes them from the working apparatus of modern automatic systems of regulation, is the great number of degrees of freedom they possess. As N. A. Bernstein's fundamental studies have shown, the essence of movement coordination, which yields a specific motor act, consists in overcoming the excess (with regard to the given motor task) degrees of freedom. It follows from this that the structure of mentally controlled effectors, while opening access to a stream of random interferences, does not in itself embody any specific programme of an individual motor act. On the contrary, a large number of degrees of freedom precludes programme constancy in the structure of the system and makes possible the realisation of a great diversity of programmes in the selfsame structure.

Modern information theory investigations of the morphogenesis of the nervous system (Eden, Platt, MacKay and others), as well as theoretical and experimental studies of the reliability of the brain (Asratyan, Kogan), lead to the conclusion of a stochastic method of organisation of the functional elements of the brain. It follows already from this method of organisation of the central elements of the nervous system that a concrete programme of motor acts can no more be included in the structure of the central units of the organism's control system than in the construction of its working organs. It is natural that such a concrete programme of action is not included in the very structure of the input analyser apparatus of the

nervous system. Thus a structurally determined programme of object motor (especially labour) behaviour is in fact excluded. It could be expected that the stochastically fortuitous character of the relations between the central structural elements of the brain corresponds to a similarly fortuitous nature of organisation of motor behaviour, i.e., that between the structure of the system and the organisation of its effector reactions there is the same correlation as in modern self-organising engineering systems operating on the principle of random search (for example, Ashby's homeostat). In this case the programme of the motor act would not be a manifestation of internal directed organisation of the control process, but only the passive result of a random scanning of chance reactions. However, even the experimental studies of representatives of the behaviourist "trial-and-error" doctrine (Small, Denis, McFarland, Adams, Watson, Lashley and others), to say nothing of modern studies of motor behaviour (Anokhin, Beritov, Bernstein, Zaporozhets, Bartlett and others), clearly show that the random scanning of trials is not a universal principle of organisation of behaviour, but a very special case, and not only in man, but in animals as well.

Thus, if the programme of a mentally controlled motor act is not structurally determined or is not the result of random scanning, the signals of information circulating in the system and effecting the control inevitably prove to be its carrier.

N. A. Bernstein's studies have very definitely shown that the command information signals coming directly to an effector organ cannot of themselves be carriers of a programme of action. Since muscular effort is a function of two variables, there is no one-value dependence between the effort and the resultant movement. That is why one and the same effector pulse may evoke different resultant movements. "Not even the finest analysis could find signs or elements of coordination in the effector pulse; they are not there."* But, if *command* information cannot be the carrier of a motor act programme, *informative* signals, from which effector commands are drawn on the basis of

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* N. A. Bernstein, *On Construction of Movements*, Medgiz, Moscow, 1947.

appropriate recoding, remain the only carrier. As regards the elementary level of mental control of object actions, such programme carriers are the simplest "first signals" of informative data (sensations, perceptions, impressions). It follows from this that the main features of mental control of object actions must be correlated with the organisation of the informative signals with which the programme of action is connected and which control that action.

The problem of further analysis consists in elucidating the connection of the features of mental control with the form of organisation of the image signals which effect this control. Since the form of organisation of the control signals and the methods of assigning a programme of action in engineering automatic systems are not a black box, the problem of the method of organisation of the control signals, which ensures the specific features of the organisation of object action, may be solved on the basis of a comparative characteristic of mental control and automatic control.

An examination of the main modern automatic systems (automatic pattern-recognition, rigid automatic control and automatic regulating systems, analogue and digital computers) reveals that in all these technological systems information operates in the same general form in which nervous processes, both discrete and gradual, are organised, i.e., in the form of code signals. According to the very physical essence of the transformations which are effected by input transduces incoming information is *coded* in the alphabet of the control circuit. The signals circulating in the circuit are then subjected to various recoding which preserves, however, their code form.

An examination of automatic systems also shows that this form of signal organisation entails the necessity of partly building the programme of operations into the system (in the design of executive elements and the relations which realise the element-by-element isomorphous correspondence of the current values of informative and command signals).

The fundamental principle of construction of *mentally regulated* action is coordination, as the overcoming of excessive degrees of freedom in the executive apparatus. Any factor of such overcoming that is not built into the

design must necessarily be provided in the organisation of control signals. Additional limitations to the conditions of isomorphism, which determine the structure of the image as a metric invariant (compared with the general form of code signals), exclude all cases of ordering in which relations between the signal set and source set do not remain invariant. Any invariance of relations is essentially a limitation to possible variety and therefore leads to a decrease in the number of degrees of freedom. The reduction in the number of the degrees of freedom in going over from the code to the image, which excludes free variation of relations between the elements, is analogous to the reduction in the number of degrees of freedom in physical bodies in going over from an uncoordinated set of their individual elements to their object integrity.

Thus, movement coordination, as an overcoming of excessive degrees of freedom of the effector output, is apparently based on Ashby's law of necessary variety, manifested in the given case in the form of the preservation of the total number of degrees of freedom of input signals for the realisation of a certain motor problem. That is why the aforesaid general principle of organisation of movement runs as a unifying pivot through the main features of mental control to which it gives rise.

Thus the objectness of action manifested in the conformity of spatio-kinematic organisation of movement with the structure of the object is determined by the fact that the signal images which programme and control the action, unlike the general case of signal codes, preserve the "individual geometry" of the source of information invariant. Since the image reproduces a specific spatio-temporal characteristic of the object, it can serve as the carrier of the corresponding object programme without the components of the latter being built into the control system.

The integrated coherence of actions in which connections between signal and reaction are not of an element-by-element character, the variability of the solutions (paths, postures, methods), generalisation of actions, switching ability of the effector elements and, lastly, the universality of the system of mental control are determined by the correlation of the geometry of the signal image and the kinematics of the movement it controls. The image of the

object and the conditions of action reproduces the geometry of *three-dimensional space or two-dimensional surface*. The path of the movement which effects the operation of this object is always a *line* in some way or other fitting into the structure of the given spatial domain. But the image of the given spatial domain includes not only the path of the possible movement, but a whole family of lines lying within the given spatial structure. Thus the geometry of the image of the spatial situation of the action potentially determines the kinematics of the set of paths of movements which realise the given action. The signal image, which by the very organisation of the image determines the general object structure of the action whose initial programme it carries, does not predetermine, within the limits of this structure, the selection of the different variants of the family of motor solutions inherent in the structure of the image. Such a multiplex form of programming by means of image structure creates the possibilities of selection which at the elementary level of sensory control is effected according to laws of chance, i.e., are determined statistically, and at the level of intellectual control form man's conscious, voluntary activity. Man's free choice and volitional behaviour thus turn out to be a special, socially-determined, case of the general principle of mental action control which at the elementary level manifests itself in the universality of motor possibilities and variability of motor solutions jointly determined by the structure of the signal image.

The potential givenness of a whole *family* of motor solutions with regard to the *actually realised variant* creates a redundancy which is here based not on a reservation of elements of the *construction*, but on the presence of reserve possibilities in the *very structure of the signal image* that programmes and controls the action.

The redundant possibilities of changing routes and switching over executive elements immeasurably increase the probability of faultless functioning of the system, or the reliability of the mental controls.

The aforementioned limitation of the degrees of freedom of the image, as compared with the general code form of the signal, creates such a definiteness of relations between the elements of the set that the position of the series of elements predetermines the position and signs of the

elements adjacent to the given ones. That is why the superposing of noise on various components of the image cannot disturb the authenticity of the perception and identification of the object, which considerably increases the noise resistance of sensory controls. As for the deficiencies in precision of mental control established by experimental psychology, they are apparently due to the fact that here no rigid single-value connection between the individual element of the set signal and the individual element of the reaction is preserved within the integral correspondence of the signal image and the structure of the object action. Element-by-element precision is by the very principle of control sacrificed to its plasticity, stability and final integral authenticity.

The duration of a control cycle (fractions of a second), in which man also considerably lags behind engineering automatic systems, is connected with the fact that the transformation of an informative signal into a control signal (which in technical systems takes place element by element) is here preceded by a process of organisation of the signal image which then controls the action as an integral structure.

An analysis shows that the main specific characteristics of mental control can be derived, at least in general outline, from the spatio-temporal organisation of signal images as a special case of signal codes. This provides an objective solution to the question of the perception image belonging to the category of signal images and its specificity compared with the nervous process organised in the general form of a code. At the same time it is fundamentally important that a comparative analysis reveals the objective "working" expression not only of those features of the image that distinguish *any* image from the general form of the signal code, but also the specific empirically disclosed properties of the image precisely as a *mental image* (projection, integrity, correspondence of representation of the natural size, relief and movement relatively independent of the image carrier's own spatio-temporal characteristics, etc.).

CONCERNING THE CONSTRUCTION OF A MENTAL IMAGE

According to all of the preceding analysis, it appears that an image is, both by its regulatory function and its informational structure, a mental image as a specific form

of signals. This raises the following fundamental question of the analysis without which the problem of developing mental-image analogues cannot be solved: the question of the mechanisms that ensure the transformation of the nervous process as a *code* into perception as a set of elements, forming the *signal image* with all its specific features. It is the question of the mechanism of decoding the nervous code, which is not provided for by the existing functional scheme of the analyser's work, but which constitutes one of the bases of the structure and control functions of the image. According to the very essence of its mechanism, decoding is a reproduction at channel output of the states which occurred at its input. Such states at the input to the analyser, which feed in information about the object, are *states of stimulation*. On the other hand, the analysis of the reflex mechanisms of the analyser's work has led to the conclusion that the image is an effect of analyser reflex acts. That is why the decoding mechanism we are seeking can only be such a specific case of neuroeffector transformations in which the *effector* links of reflexes reproduce the input *states of stimulation* of the receptor apparatus. The question is: are there reflex acts with such a type of neuroeffector transformations which, while they effect the decoding, reproduce the input state of stimulation in the reflex effect? The answer to this question may be produced by a review of the extensive factual material furnished by physiologic and pathophysiologic studies of various types of reflexes. An examination of the experimental data furnished by the studies of various exteroceptive, visceromotor, viscerocutaneous and viscerovisceral reflexes (A. V. Dolin, L. N. Rubel, A. D. Speransky, N. I. Krasnogorsky, D. K. Martynyuk, M. I. Mityushov, S. M. Leites, Z. N. Krylov, M. R. Mogendovich, K. Kh. Kekcheyev and others) shows that there is a large class of reflex acts which reproduce, as an output reflex effect, various types of initial input states that effect the initial stimulation. Thus, for example, the chemical state, which in the initial conditions existed under the stimulating influence of light, is reproduced as an effect in the photochemical reflex by a conditioned reflex method. In N. I. Krasnogorsky's well-known experiments the reflex reproduces the movement of the dog's paw, which in the initial experiment served as a kinaesthetic stimulus. Here

the output effect reproduces the input state, realising, in the true sense of the word, the decoding process. A similar example which at the same time is directly related to the mechanism of image construction is the ideomotor act where the initial state of the kinaesthetic stimulation is reproduced in a reduced form as the effect that forms the kinaesthetic sensation. Thus, there really exists a general class of reflex acts functioning according to a decoding scheme; with regard to this class the decoding process apparently appears as a special case in the construction of the image. The specificity of this case must be determined by precisely *what* is being decoded in the construction of the mental image, i.e., the specific character of the very states of the analyser, coded by the nervous code and decoded as a reflex effect. Here the question arises: can any input state of the analyser be an element of the set of states whose organisation in a synthetic ordered structure forms the mental image as a signal?

The necessity of revealing the specific characteristics of the elementary states of the analyser, a set of which forms the mental image, is determined by the fact that, unlike the general form of signal codes, the image, as an ordered set, is not indifferent to the properties of its elements. This is one of the specific features of the image as a special form of code.

Extensive experimental material containing specific energy and spatio-temporal characteristics of the elements of the image set is found in various data on differential thresholds which by the very fact of their existence attest the presence of elementary components of the sensory structure. It is no accident that modern investigators (Bekeshi, Stevens) interpret the value of the differential threshold as a *quantum of sensory discrimination*.

The energy and spatio-temporal features of the image elements are connected with the modal characteristics of the states of interaction of the analyser and object which form the physical basis of the image element. The nature of these input states of interaction is in its turn determined by the peculiarities of the physical properties of the objects, information about which enters the analyser. To solve the fundamental problem of the modal characteristics of the elements of the mental image, it is necessary to determine the category of physical properties of the

objects, the state of interaction with which possesses the requisite qualities of the *initial image material*. The limitations imposed by the specific features of the image on the qualities of its elements must serve as criteria in this search. An analysis shows that the most general limitations are the *macroscopic nature* of these properties and the *inseparability of their physical characteristics from their spatio-temporal structure*.

On the basis of the two aforesaid criteria, the totality of the properties of the objects—information sources—breaks down into three groups from which by two successive dichotomic choices it is possible to isolate the group of physical properties, the state of interaction with which forms an authentic physical basis for the elements of the mental image.

The thus isolated group of macroscopically integral properties of objects, inseparable from the spatio-temporal structure and not acting from a distance (hardness, resilience, roughness, etc.) is the content of reflection in tactile-kinaesthetic sensations. Since the interaction of the analyser with this group of properties, which satisfies the requirements of the two aforesaid criteria, contains an adequate physical basis for the material of the mental image, all other types of sensory images necessarily borrow the sources of their specific object structure from the tactile-kinaesthetic sphere. This determines the genetically initial place of the tactile-kinaesthetic sphere which has long since been pointed out by philosophers, psychologists and physiologists. An expression of these relations is the fact that tactile-kinaesthetic sensations are ontogenetically primary and are formed on the basis of the unconditioned-reflex analyser mechanism. On the other hand, it is precisely the absence of an adequate physical basis for the image in the stimuli of distant analysers that makes necessary a later ontogenetic development of the functions of these analysers according to the mechanism of the conditioned-reflex interconnections with skin and muscle sensations (which was especially pointed out by Pavlov and Ukhtomsky). The same causes determine the lack in distant analysers of coincidence of direct stimulation and the object of perception which underlies the fact that distant sensations are of a more *mediate* character. Thus, for example, there is no such direct relationship between

copy and original in respect of colour sensation and wave-length as exists between the image of shape or resiliency and the actual shape or resiliency of the object.

In the general structure of the object image these mediated components preserve the code character, but the code itself, as was shown, is a method of organisation of information processes connected with the source of information by relations of isomorphism.

The encoding transformation at the receptor output converts the component of the continuous series of initial physical and physiologic states to a nervous impulse as a discrete element of a frequency code, thereby effecting the quantisation of the continuous series in accordance with the threshold characteristics of the nervous impulse.

In the central cortical analyser apparatus the nervous code is recorded, the various afferent-effector connections are synthesised and the centripetal impulses are transformed into centrifugal impulses, the latter then being subjected to neuroeffector decoding. The decoding neuro-effector transformation, reproducing the initial state as a reflex effect, converts the nervous impulse as a discrete element of the frequency code back to a sensory quantum as an element of a continuous mental image. But an individual element of a mental image reproduces only the characteristics of a corresponding individual element of the object. However, a mental image as an integral object image, being a metric invariant, reproduces the totality of the spatio-temporal properties of the source beginning with the characteristics of the spatio-temporal series common to space and time and ending with the topological, projective and other properties of space, including the metric properties. From this alone it follows that, to construct an image as a set of elements, the receptive field of the analyser must embrace all the components of the spatio-temporal structure of the object. Studies of touch and vision show* that in the analysers this does not occur according to the principle of parallel action. Under conditions of parallel action an authentic image of natural spatial properties would be restricted by the size and number of dimensions of the receptive surface. In the most

* See Wekker L. M. and Lape U. P., "Concerning Construction of a Tactile Image", *Problems of Psychology*, No. 5, 1961.

general case metric invariance would not be ensured. That is why this requires a combination of parallel and successive embracing, which is realised by scanning. It is no accident that an integral metric image is formed in *vision* and *touch*, i.e., precisely in the analysers whose executive apparatus performs sensory actions which successively embrace the spatial properties of the object, i.e., scan.

If the temporal characteristics of scanning agree with the inertia values of the initial states of the analyser forming an element of the image, the successive temporal series in the decoded image is again transformed into a simultaneous spatial structure. This is reliably attested by the fact of simultaneous sensing of a TV frame traced out successively by the electron beam scanning the screen. The results of a study now being conducted by the author show that this type of transformation of a temporal series into a spatial series also occurs at much slower scanning speeds than those employed in standard television.

Thus construction of a mental image as an ordered set of elements is effected by coding, reflex decoding and motor scanning of a continuous series of initial states in which spatial and temporal components are converted into each other.

This principle of scanning, which organises the spatial structure of the image by preserving the continuity of the temporal series of initial states, ensures the non-coincidence of the space of the image with the space of the "screen" of the analyser and, contrariwise, the coincidence of the space of the image with the space of the object.

The nature of the synthesis and scanning of the image thus determines the characteristics of the mental image as a signal, which distinguish it from physical or technological image signals.

To lock the elements of the image in a continuous series, the decoding pulse must apparently reach the receptor not later than the "reserve of inertia" of the preceding elementary state of the analyser will have been exhausted. Thus the results of a study of the perception of successively acting elements of a contour (by cinema presentation) show that perception of a contour as a *simultaneous spatial* structure the scanning interval for the entire contour must be approximately in the neighbourhood of the limits of the inertia time of vision, which may reach

about 300 milliseconds. If the continuous series of formed elements of the image is a set of changing states, corresponding temporal characteristics of the reflex cycle of image construction lead, as studies of touch show, to representation of movement (Wekker, Lape).

The relations between the elements of the image and the elements of its screen characteristic of the mental image also arise from the spatio-temporal principle of scanning. Our studies show that a set of image elements lying in the line of scanning may correspond to one element of the receptor surface. This precludes the breaking down of the image into different elements of the substrate and creates the basis for the functional integrity of the image, which is erroneously interpreted by Gestalt psychology as a kind of initial configuration.

Moreover, if we impose on the process of image construction additional limitations which conform the rate of scanning to the volume of the set of elements that is synthetised into a continuous whole, we can derive from this image scanning mechanism those of its characteristics which arise from the congruence of the metric invariant to its object. Thus with an appropriate ratio of the rate of scanning to the inertia time of individual elements of the image the *first* and *last* elements of the series find themselves in a continuous structure, successiveness changes to simultaneity—"simultaneation of successiveness" (Goldstein). Temporal characteristics of the image are thereby converted into spatial characteristics. If at this time images of elements of the object, the distance between which exceeds the size of the receptor surface, find their way into this simultaneously spatial structure, then (given commensurate conversion of duration into length) there arises such a property of the image as *representation of the natural size of the object regardless of the dimensions of the receptor element*. If the representation of the elements of the received spatial fields *divided by the third dimension* finds its way into such an integral structure, an authentic reflection of the object's relief and of its *three-dimensional background* is formed. The last property of the image produces a distant projection ("externalisation"). If the coordinates of the individual components of the simultaneously-integral structure of the field change against the

background of this structure, the level of representation of movement which takes place in visual perception arises.

The analysis thus shows that from the *general reflex mechanism of image construction we can derive all the main characteristics of the mental image, which distinguish it from the general form of signal codes, as well as from signals realising conventional physical or technological images.*

In order that the perceptive device, which models the structure and functions of the mental image, may possess the high operating characteristics (reliability, stability against interference, universality, etc.) which are typical of mental control, and for the achievement of which attempts at bionic analogue simulation are made, it is necessary to take into account and reproduce in the functional scheme the features of the mechanism of the analysers which underlie the specific features of the mental image as a signal considered in this article.

ORIENTING REFLEX AS INFORMATION REGULATOR

By Y. N. SOKOLOV

1. CRITERION FOR ISOLATING THE ORIETING REFLEX AS AN INDEPENDENT FUNCTIONAL SYSTEM

Introducing the concept of the orienting reflex, as a special unconditioned reflex, Pavlov emphasised both the peculiarity of the factors which evoke this reflex and the specific character of the adaptational importance of the separate reactions (components), which make up this reflex act, to the organism.

As a special stimulus of the orienting reflex, he pointed out the "novelty" of the stimulus and, as its biological significance—the set of receptor to facilitate the reception of the stimulus. Pavlov wrote: "Upon appearance of new agents in the animal's environment (by this I also mean the strength, new intensity of old agents) the organism sets up in their direction appropriate receptor surfaces for the best possible impression of the external stimulations."*

The fact that the orienting reflex is associated with a corresponding set of receptor at first gave Pavlov reason to regard this reflex as a set reflex. "Before us is again a fatal reaction of the organism—a simple reflex which we call an orienting, set reflex."**

Subsequently, however, he relinquished such identification of orienting and set reflexes. As a matter of fact, there are set reflexes (muscular reactions of change in posture), which are not excited by the "novelty" of the stimulus. Afterwards Pavlov used only the term "orienting reflex", emphasising again, as an essential characteristic, the "novelty" as a special agent, and the set of a receptor surface as an expression of the biological significance of this reflex. It may be said that the orienting

* I. P. Pavlov, *Complete Works*, Vol. III, Moscow, Publishers of the U.S.S.R. Academy of Sciences, 1949, p. 109.
** *Ibid.*

reflex is such a set reflex whose special agent is the "novelty" of the stimulus.

Inasmuch as the orienting reflex was usually studied by observation of its external manifestations in the reactions of the skeletal muscles, the motor components (movements of the ears, eyes, head, body) began to be regarded as the only manifestation of the orienting reflex, and the participation of the skeletal muscles—as its essential characteristic. This point of view was given expression by A. A. Biryukov: "... We see the essence of the concept of the orienting reflex in emphasising its muscle-setting nature."*

From this point of view the respiratory, vascular and other components are regarded as collateral, secondary manifestations. Suffice it to analyse the animal's "sniffing" as a manifestation of the orienting reaction, directly connected with the change in the respiratory acts, to see the groundlessness of this assertion. Analogous examples may be cited with regard to "orienting" salivation associated with an increased reactivity of the taste analyser.

Since the reactivity of an analyser depends not only on setting up a peripheral receptor surface, but also on the functional state of the higher parts of the brain, the muscle-setting is not the only way to increase the reactivity of the analyser, and all the reactions associated with the intensification of the functional state of the analysers may be ascribed to the system of the orienting reflex, providing they arise in connection with the "novelty" of the stimulus.

Those who regard the orienting reaction as a reaction to the "novelty" of the stimulus usually imply two different phenomena:

a) the reflex arising at the moment of application of the stimulus later disappears against the background of the continuing action of the stimulus; upon removal of the stimulus the reflex reappears;

b) arising upon the first appearance of the temporarily acting stimulus the reflex then weakens and completely disappears during repeated applications of the stimulus.

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* A. A. Biryukov, "Concerning the Question of the Nature of the Orienting Reaction". In book: *Orienting Reflex and Orienting-Exploratory Activity*, Moscow, Publishers of the R.S.F.S.R. Academy of Pedagogical Sciences, 1958, p. 24.

These two characteristics of "novelty" are not equivalent. The first may occur in decorticated animals, the second is, in higher animals, clearly associated with the cortical mechanism.

The ability of the reflex to disappear in the course of the continuing action of a stimulus is not a sufficient indication of the orienting reaction. The point is that, as the stimulus continues to act, such unconditioned reflexes which are clearly not orienting may also disappear. For example, the heat regulating vascular reflex may disappear in the course of a long-acting weak or locally applied thermal (for instance, cold) stimulus.

Thus it is not the disappearance of the reaction upon prolonged application of the stimulus that is an essential characteristic of the orienting reaction. This also occurs in other unconditioned reflexes. Removal of the stimulus in this case evokes an opposite reaction.

In evaluating the orienting reflex it is necessary to consider the sign of the reaction upon the change in the stimulus.

Only the reaction whose sign does not depend on the direction of the change in the stimulus may be regarded as a true orienting reaction to the "novelty".

In other words, the critical characteristic is the non-specific character of the reaction with regard to the changes in the intensity of the stimulus.

The simplest explanation of the mechanism of such non-specificity of the orienting reaction with regard to the power characteristic of the stimulus may be the idea of the role of the "on" and "off" elements as agents of the orienting reflex.

The aforesaid criteria for differentiating the unconditioned reactions are applicable to a characterisation of the origin of the orienting reaction against the background of its extinction as the result of repeated application of a stimulus. It was precisely the extinction that many authors assumed to be the main characteristic of the orienting reflex. Thus, according to L. A. Orbeli, the specific feature of the orienting reflex is that it arises as an unconditioned reflex, proceeds as a conditioned reflex and is extinguished upon repeated application of the stimulus.*

* See L. A. Orbeli, *Problems of Higher Nervous Activity*, Moscow, 1948.

However, extinction cannot be considered a characteristic sign of the orienting reflex without essential reservations. The thing is that the phenomenon of extinction can also be observed in other reflexes upon repeated application of a stimulus. Such, for example, is the extinction of the adaptational pupillary reaction during repeated application of weak light stimuli (Y. N. Sokolov, 1958). An anologous phenomenon is observed in cases of adaptational vascular reflexes (O. S. Vinogradova, 1961).

A characteristic feature of the orienting reflex is not only the effect of extinction, but also that the reaction is independent of the direction of the change in the agent applied.

The criterion of the "independence of the sign of the reaction from the direction of the change in the stimulus" requires a more precise definition. The point is that after extinction of the adaptational reflexes to weak specific stimuli, for example, after the pupil ceases to contract in response to the action of weak light, both weakening and intensification of the light evoke the specific reaction of contraction of the pupil.

The same sign of the reaction does not make it possible to differentiate the extinction of the orienting reaction from the extinction of specific reflexes. This is precisely what A. R. Shakhnovich fails to take into account in regarding the contraction of the pupil as an orienting light reflex during a change in the stimulus.*

A specific, for example, heat-regulating reflex is also restored with the same sign that was possessed by the reaction which was being extinguished. The change in the stimulus after extinction of the reactions to heat restores the reaction of dilatation of the vessels, whereas the change in the stimulus after extinction of the reactions to cold restores the effect of contraction.

The parallel registration of the heat-regulating and electrodermal reactions has shown that the "novelty" stimulates both the extinguished orienting and the extinguished heat-regulating reflexes.

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* See A. R. Shakhnovich, "On the Pupillary Component of the Orienting Reflex under the Action of Vision-Specific and Non-Specific Collateral Stimuli". In book: *Orienting Reflex and Orienting-Exploratory Activity*, Moscow, Publishers of the R.S.F.S.R. Academy of Pedagogical Sciences, 1958.

Thus it may be concluded that it is not the "novelty" of the stimulus which is itself a characteristic of the orienting reaction, if it is a question of the effect of extinction, but the peculiarity of the unconditioned orienting reaction which may be characterised as non-specific with regard to all changes in the stimulus. It follows from this that, speaking of the "novelty" factor during extinction, it is necessary to remember the possibility of disinhibition of the adaptational reflexes upon a change in the stimulus used during extinction. The effect of appearance of the orienting reaction proper and the restoration of the specific adaptational reflex may coexist, entering into complex interaction if the effector mechanisms of these reflexes have common executive organs.*

Since during extinction a stimulus may be new only with regard to the traces left in the nervous system by the stimulus used earlier, it is necessary to suppose that not the afferent signals themselves are the source of excitation of the orienting reaction, but the impulses of discoordination which arise at the moment when the new stimulus does not coincide with the formed trace—"nervous model of the stimulus".

Thus in characterising the orienting reflex it is necessary to emphasise not only the property of extinction, not only the fact that the agent of the reaction is the "novelty" of the stimulus which is determined by the degree of the failure of the signal being received to coincide with the "nervous model of the stimulus" formed in the nervous system but also the non-specific character of the reaction in all changes.

2. ORIENTING REFLEX AND ACTIVATION REACTION

If we assume that the orienting reflex is evoked by impulses which arise due to discoordination of the stimulus with the nervous model, it becomes easy to explain the fact of the relative independence of this reflex from the strength of the stimulus and the direction of the change in the quality of the stimulus.

The relatively non-specific character of the orienting reaction arising under the action of different agents agrees

* See Y. N. Sokolov, *Perception and the Conditioned Reflex*, Moscow, 1958.

with the data on the fact that both the centripetal and centrifugal impulses converge in the cells of the nuclei of the reticular formation.

In addition to the muscle set components of the orienting reflex it is necessary to remember the externally unexpressed changes in the reactivity of the receptor systems associated with the change in the functional state at various levels of the analysers.

The electroencephalographic component of the orienting reflex consisting of changes in the background rhythm of the electric activity of the brain has been studied the most thoroughly. Two of its forms may be pointed out: the activation reaction, usually associated with a depression of the alpha-rhythm, and the awakening reaction associated with the transition from the slower rhythm to higher-frequency alpha-waves. The changes in the background rhythm possess all the features of a reflex, i.e., they are not merely a result of the afferent impulses reaching the cortex, but arise as a reaction to the coming of these impulses along with other vegetative reactions. In this sense the depression of the alpha-rhythm is the same reaction as the electrodermal or the oculomotor reflexes. This is manifested in particular in the latent period of this reaction, which is longer than the time required for impulses to reach the cortex from the periphery. It may be assumed, on the basis of R. Kornmüller's data (1960) that the changes in the background rhythm reflect the activity of the neuroglia cells, which affects the functional state of the neurons and is the effector part of the activation reflex (Y. N. Sokolov, 1960).

This idea agrees with the data of Golambos (1960) who devoted special attention to including glial elements in the process of reflex regulation. L. A. Orbeli emphasised the role of the sympathetic system in the regulation of the general level of the functional state of the cortex. Consideration of the depression of alpha-rhythm as a reflex response may help to understand the regularities of this reaction as a component of the orienting reflex.

Investigation of the electroencephalographic component of the orienting reflex gives rise to the question of distinguishing a local and a generalised orienting reflexes (Y. N. Sokolov, 1958).

In connection with this it is necessary to define more precisely the concept of "non-specificity". In using the term "non-specific character" above we implied that the composition of the orienting reflex does not depend on the quality of the stimulus. In this sense non-specificity is not a characteristic feature of a local orienting reflex associated with an adequate stimulus. However, the fact that precisely the "novelty", i.e., the impulses of discoordination, is its stimulus remains valid also for the local orienting reflex.

It is more difficult to distinguish the tonic and phasic electroencephalographic components of the orienting reflex.

S. Sharpless and H. Jasper (1956) associated their mechanisms with different levels of the reticular system and identified the tonic orienting reflex with generalised activation processes in the cerebral cortex, and the phasic component with local processes.

This identification is at variance with the data when the local orienting reflex is characterised by tonic stability (depression of the alpha-rhythm in the occipital region during visual attention) and the generalised reflex—by properties of a brief phasic reaction (depression of the alpha-rhythm in various areas of the cortex under the action of sound).

When characterising the tonic orienting reaction it should be remembered that this reaction may be evoked at the moment the stimulus changes and is subsequently retained at a high level also in the absence of the stimulus or under its prolonged action.

In this case no such property of the orienting reaction as a return to the initial level against the background of continuing stimulation is observed. To be sure, practically it is usually a question of relative prolongation of the reaction. But the fundamental difficulty remains. It pertains to the criterion which makes it possible to single out the tonic orienting reflex among the different tonic reactions.

A tonic orienting reaction may be evoked by both an intensification and weakening of the agent. This is particularly clearly manifested in the awakening reaction when the new level of activity stably persists after removal of the stimulus. However, the analysis of a tonic orienting

reaction is complicated by the fact that the level of cortical activity may essentially depend on the level of intensity of the acting stimulus.

A stable increase in the excitability of the central nervous system in light and its functional weakening in darkness may serve as an example of such influence.

The question is: to what extent are these changes in excitability tonic orienting reactions? It may be assumed that the orienting tonic reactions are, in the true sense of the word, only such changes in the functional state, which do not depend on the sign of the changes in the stimulus.

From this point of view not all the effects of electroencephalographic activation connected with increased excitability are of an orienting nature, but only those which do not depend on the directions of the change in the intensity of the stimulus.

Let us examine the peculiarities of electroencephalographic reactions to light and darkness. The stable increase in excitability in the light is a special effect closely related to posttetanic potentiation which rather resembles specific reactions. This is attested by stable diminution in activity in the dark. The orienting mechanism of these reactions is determined by the extent to which excitability increases with the novelty of the agent at different directions of change in the strength of the agent.

Not all changes in the functional state of the analysers, associated with the orienting reaction, are reflected in the changes in the background rhythm. The orienting reaction is reflected in the changes of the evoked responses and, in particular, in the change in the driving reaction which arises during rhythmic stimulation with light. This change in the evoked potentials is primarily reflected in the faster cycles of excitation, as a result of which a predominant increase in reactions to high frequency light flashes is observed.

The facilitation of the evoked responses is a special component of the orienting reflex and may be evoked by direct stimulation of the reticular system (S. Dumont and P. Dell, 1960).

The most typical characteristic of facilitation is the decreased duration of the cycle of excitation and not the increased amplitude of the response. That is why, as A. M. Maruseva (1960) has shown, on infrequent stimula-

tion the facilitation of the auditory system may be accompanied by a decreased amplitude of the evoked potential. It is possible to set apart a local (facilitation of the potentials of the visual cortex under the action of light) and a generalised (facilitation of the potentials of the visual cortex under the action of sound) facilitation by analogy with the classification of the orienting reflex accepted earlier. S. Dumont and P. Dell (1960) designate the analogous differences in facilitation as specific and non-specific facilitation.

Facilitation, apparently associated with the regulation of synaptic conduction, is manifested at various levels of the analyser. It applies particularly to the peripheral parts of the analyser. Thus the orienting reaction exhibits facilitation of responses of the retina of the rabbit's eye (Y. N. Sokolov, 1960) and responses at the level of the optic chiasm, optic nerve, optic tract and the lateral geniculate body (Y. N. Sokolov and V. P. Dulenko, 1960).

Thus facilitation is associated with increased reactivity at all levels of the analyser even when it is not possible to observe any essential changes in the background rhythm of the EEG.

Facilitation is apparently closely associated with the sensory component of the orienting reflex which is characterised by increased sensitivity measured on the basis of a verbal report on a person's sensations. But since the absolute threshold essentially depends on peripheral adaptation the electroencephalographic component of the orienting reflex and the effect of facilitation do not always exactly coincide with the change in the absolute threshold which characterises the sensory component.

The effect of disinhibition may be regarded as a special component of the orienting reflex. It is well known that, if a new agent is applied after extinction of the orienting reflex to one stimulus, the reaction to the former stimulus is for some time restored. This restoration may not be accompanied in a noticeable form either by the effect of facilitation or by a stable change in the background rhythm.

The effect of disinhibition may be explained by deblocking of the pathways leading to the nuclei of the reticular formation which is the centre of efferent integration of the orienting reflex (Y. N. Sokolov, 1960).

All our inferences concerning the connection of the changes in the functional state with the tonic orienting reflex also apply to these reactions.

Thus a number of phenomena of facilitation and activation of the analysers do not belong to the system of the orienting reflex since the direction of these changes depends on the direction of the changes in the acting stimulus. Only the forms of an intensified functional state, which do not depend on the direction of the changes in the stimulus, belong to the system of the orienting reflex.

Thus the change in the functional state under the action of a stimulus is formed of:

a) the power effect of the stimulus (activation, potentiation, facilitation) determined by the intensity of the stimulus;

b) non-specific, orienting intensification associated with the moment of the change in the stimulus.

From this point of view activation, as a component of the orienting reflex, must be distinguished from the activation reaction in general which implies all cases of intensification of the functional state.

A component proper of the orienting reflex is such an intensification of the functional state, which is independent of the direction of the changes in the stimulus.

A new trend in the studies of the orienting reflex is investigation of its mechanisms at the cellular level. Thus, the work of Hughbel et al. (1959) demonstrated the existence of "attention cells" (in the auditory cortex) which reacted only when the stimulus evoked an orienting reaction.

The activation reaction at the cellular level may also manifest itself in that the usually non-reactive neurons (type *A* according to Young's classification) become active. Moreover, the processes of origination of streams of nervous impulses in interdependent type *B* and type *D* neurons become faster. As a result, the reaction time to a flash of light, consisting of the appearance of a group of impulses, decreases. The lability of the neurons, determined by the highest frequency of following the frequency of the rhythmic stimulus, increases. Since the highest frequency of the stimulus reproduced by the neuron characterises the amount of transmitted information it may be inferred that the origin of the orienting reaction causing an increase

in the highest frequency is associated with the increased velocity of transmission of information to the central nervous system.

In addition to the EEG reaction, activation and facilitation evoked by potentials directly associated with the orienting reflex it is also necessary to remember at the neuron level the activating effect of the stream of afferent impulses coming from the receptors when the orienting reflex, as a special reaction to the "novelty" of the stimulus, is absent. Posttetanic potentiation may serve as an example of this effect. This phenomenon also arising at the level of cerebrospinal reflexes is associated with an increase in the postsynaptic potentials after prolonged high-frequency stimulation (P. G. Kostyuk, 1960). An analogous phenomenon is observed in the visual area upon application of flashing light (O. P. Makarov, 1960). If the orienting reaction arises only at the moment of change in the stimulus, the potentiation gradually increases in the course of the stimulation, stably persists as long as the stimulation lasts, and gradually disappears after the end of the stimulation. Although the potentiation externally resembles the tonic form of the orienting reflex, the fact that potentiation occurs in a preparation of the spinal cord and isolated retina and that it disappears and is replaced by inactivation in the absence of stimuli attests that these phenomena are essentially different.

At the same time the similarity of the expression of posttetanic potentiation with facilitation and activation in the orienting reflex denotes that they have common mechanisms. It may be assumed that facilitation, as a component of the orienting reaction, is conditioned in the main by a centrifugal activating influence on the reticular formation and through it on various parts of the analysers, while potentiation under the influence of light (Chang's effect) and posttetanic potentiation of cerebrospinal reflexes (Eckles) are a result of direct influence of afferent impulses on the mechanism of synaptic transmission.

Under natural conditions the action of a stimulus is attended with interaction of both forms of activation: increased excitability of the analysers under the influence of afferent impulses on synaptic transmission, and facilitation depending on the origination of impulses of discoordination in response to the new stimulus. The mechan-

ism of this latter effect is associated with the return influence of the cortex on the reticular system and through it, apparently with the participation of the adaptational-trophic function of the vegetative nervous system, on the metabolism of the synaptic transmission. The essential difference between these two effects is that facilitation, as a component of the orienting reflex, depends on the "novelty" of the stimulus and becomes extinguished on repeated application of the stimulus. As for posttetanic potentiation and potentiation of the retina with light, these phenomena depend directly on the strength of the stimulus, increase during stimulation and are not extinguished on repetition.

Interaction of the impulses of discoordination and afferentation associated with the coming of impulses to the centres of the reticular system apparently also takes place in all other components of the orienting reflex. This is manifested in the fact that in cases of equal "novelty" of the stimuli the orienting reaction is the more intense, the stronger the stimulus. It may be supposed that the excitation may reach the effector cells which integrate the orienting reaction in two ways:

a) through collaterals leading from the specific pathway to the reticular system;

b) through corticifugal connections in the form of impulses discoordinated in cases of failure of the stimulus to coincide with the nerve model.

In such cases the pathway through the collaterals ensures the dependence of the reaction on the strength of the stimulus, while the impulses of discoordination determine the effect of "novelty" in pure form.

The extent of participation of both ways of excitation determines the way the reaction proceeds—whether or not it depends on the strength of the stimulus. Against the background of extinction of the orienting reaction in response to a stimulus of certain strength the appearance of the reaction on weakening or strengthening of the stimulus is determined by impulses of discoordination, and the absolute strength of the stimulus loses its significance. If extinction is absent, the law of strength with regard to the orienting reaction manifests itself particularly clearly.

3. EXTINCTION OF THE ORIENTING REFLEX AND ASSOCIATED PHENOMENA

The well-known phenomenon of extinction which exhibits all the features of elaboration of the inhibitory conditioned reflex is observed during repeated application of a stimulus. The following phenomena occur during extinction:

a) elaboration of the "nerve model of the stimulus" (trace corresponding to the applied stimulus) and cessation of impulses of discoordination in virtue of the coincidence of the stimulus and its nerve model;

b) blocking of the pathways leading from the specific pathways to the reticular system by the conditioned inhibitory reflex mechanism;

c) weakening of the functional state of the brain by the conditioned reflex mechanism (conditioned reflex sleep, conditioned reflex intensification of the slow EEG waves) when the beginning of stimulation becomes a signal of developing or increasing generalised weakening of the functional state.

Various effects of activation, since they depend on the "novelty" of the stimulus, become extinguished together with the motor, vegetative and electroencephalographic components of the orienting reflex. The phenomena of potentiation associated with the direct action of afferent impulses on the synapses remain. The suspension of the activating action of the reticular system during extinction also leads to a diminution in the general excitability of the specific afferent systems.

Y. A. Altman's experiments (1961) have shown that during prolonged action of infrequent clicks the amplitude of the responses diminishes, while the time of the excitation cycle increases. This effect, the opposite of the phenomenon of facilitation in the orienting reflex, is eliminated by adrenalin and pain, which disinhibit the orienting reflex. The inhibitory action on the specific afferent system is more strongly pronounced in more central parts of the analyser and takes place with the participation of the cortical inhibitory mechanism. In cases of extirpation of the auditory cortex the effect of inhibition disappears and is replaced by the phenomenon of potentiation when prolonged stimulation only intensifies the functional state.

The aforesaid phenomenon of inhibition of specific

afferent systems has all the features of elaboration of a special conditioned reflex and is not a mere result of synaptic fatigue, which develops according to other laws.

A change in the stimulus against the background of extinction leads to the appearance of the orienting reaction in virtue of:

a) the appearance of impulses of discoordination upon failure of the stimulus and the elaborated nerve model to coincide;

b) a deblocking of the pathways to the reticular system due to the fact that the new stimulus does not serve as a signal of inhibition, i.e., does not include the conditioned-reflex blocking mechanism.

At the same time the mechanism of the conditioned-reflex weakening of the functional state of the brain is disturbed, which affects the background rhythm of the cerebral cortex and the conditions of synaptic conduction in the specific afferent system.

4. "NERVE MODEL OF THE STIMULUS"

After achieving extinction of the orienting reflex it is possible specially to investigate the types of changes in the stimulus that may excite the orienting reflex and thus to determine the "configuration" of the nervous trace. A special investigation has shown that the orienting reaction may be excited by any discrepancy between a stimulus and its nerve model formed in the course of repeated applications of the stimulus. The nerve model includes even the intervals between the applied stimuli.

For the given property to become the stimulus of the orienting reaction the stimulus must be strictly constant during repetition, i.e., in the course of preliminary extinction of the reaction.

The most interesting are the experiments where the "nerve model of the stimulus" reflects the temporary sequence of signals equal in strength and quality. Experiments with a change in the intervals between the stimuli and a change in the duration of the signal are specific cases. Experiments have shown that the nerve model must be conceived as a dynamic process of elaboration of a "prediction" by the nervous system and comparison of the prediction with the incoming value of the signal. It may

be said that by observing the peculiarities of the incoming signal for a long time the nervous system extrapolates its future value. The orienting reaction arises if the prediction elaborated by the nervous system for the given moment of time does not coincide with the value of the incoming signal. In such cases the temporary intervals are differentiated with very high precision.

Experiments show that the central nervous system exercises continuous control over the external and internal signals which are not in the "focus of attention".

A "nerve model of the stimulus" is also formed when the stimulus becomes a signal of the response reaction. As a conditioned reflex is being elaborated, when the conditioned reaction becomes stabilised, the orienting reactions become extinguished as they do under the action of indifferent stimuli. The change in the conditioned stimulus leads to the fact that the stimulus ceases to coincide with the formed model, a phasic orienting reaction arises, and the conditioned reaction becomes the more inhibited, the more the new stimulus differs from the model formed earlier. Thus the signal of discoordination is the agent of the orienting reaction also during the action of the conditioned stimulus.

At the same time, when the stimuli acquire a signalling value, a sharp difference between the indifferent and signalling stimuli is observed. Orienting reactions to signalling agents are stronger and last longer. Against this background non-signalling stimuli often weaken or disappear altogether (O. S. Vinogradova, 1958, 1961).

The intensification of orienting reactions under the action of signalling stimuli depends on:

a) the activating action of the reinforcement;

b) the overall action of the signal and return afferentation during the realisation of the reaction;

c) an intensification of the local tonic orienting reflex evoked by the instruction and selectively spreading to the analysers which receive definite groups of stimuli.

Investigation of orienting reflexes against the background of elaboration of conditioned reflexes is noted for the fact that here the tone of the orienting reaction is higher and the phasic orienting reactions become extinguished more slowly. This makes it possible to study in detail the elements of the signal which evoke orienting

reactions. The situation in which the subject has to differentiate complex chain stimuli is the most effective. O. P. Terekhova's experiments (1957) have shown that the orienting reaction arises the most stably:

a) at the moment of application of the stimulus;

b) at the moment when the sign differentiating the stimuli is received.

These investigations were continued by L. Aran (1960) and Eckles (1961) who identified complex sound sequences resembling the signals of Morse's code. In these experiments it was also shown that the orienting reactions are the most stably preserved in the process of elaborating a differentiation of several sequences in response to application of the signal at the moments which are differentiating signs of these complex signals. If the sound stimuli which make up the complex are equal in strength, pitch and timbre, they differ only as to the place they occupy in the sequence of the sounds which form the complex. With knowledge of the complex signals which the subject has to differentiate and the frequency with which each of them appears in the experiment, as well as by observing the moments at which the orienting reactions appear and when the conditioned motor response arises, it is possible to establish the dependence of the orienting reflex of the conditioned reaction on the statistic properties of the signals.

5. ALGORITHM OF THE ORIENTING REACTION DURING DIFFERENTIATION OF SOUND SEQUENCES

The hypothesis of the dependence of the orienting reaction on the statistic properties of the signals and their information content arises in connection with the study of the peculiarities of the orienting reflex as a non-specific reaction to the "novelty" of the stimulus.

The concept of "novelty" of the stimulus is intimately connected with the idea of the function of preservation of traces of former stimulations in the nervous system of animals and man. In a physiological sense a stimulus may be new only with regard to a definite stereotype of stimulations formed in the former experience. In the case of a dog with removed cerebral hemispheres no such stereotypes can be formed and the difference between "new"

and "old" stimuli is effaced and orienting reactions do not become extinguished.

From this point of view the stimulus is new if it differs from the "nerve model of the stimulus" which formed in the course of applications of the stimulus. The more the stimulus being used differs from the formed model, the newer it is to the organism and the stronger the orienting reaction which it evokes.

Quantitatively the degree of "novelty" of the stimulus may be characterised by the value of uncertainty, i.e., the entropy which the appearance of the stimulus creates in the situation.

Let us consider the simplest situation at the moment of appearance of the stimulus.

Let the subject for some time be in a soundproof chamber as far as possible deprived of all external stimuli. At some moment a stimulus is applied over a certain period of time.

The initial probability of the hypothesis that at each successive moment of time the subject will still have to do with the absence of a stimulus is high; the probability of appearance of a signal is low; the entropy of the entire situation is close to zero. The appearance of a signal reduces the probability of the hypothesis of the absence of a stimulus and increases the probability of the hypothesis of the presence of a stimulus. During the subsequent moments of time the probability of this hypothesis increases and the uncertainty of the situation measured by the entropy decreases.

For a further quantitative analysis we shall make some additional assumptions.

The first assumption is that the signals are received at discrete moments of time. On the basis of this assumption the stimulus may be broken up into elementary portions—"quanta of time". Then the presence of the stimulus corresponding to the appearance of a stream of impulses in the nervous system and the absence of a stimulus corresponding to the absence of nervous impulses are "symbols" which make up the alphabet of this simplified code. By combining the sequence of these symbols we can produce complex signals.

The second assumption pertains to the registration by the nervous system of the probability of appearance of

complex signals and the probability of appearance of a stimulus at each moment of time.

As the "various quanta" proceed, two processes take place:

a) the probability of one of the hypotheses, as to which signal the subject receives, increases;

b) the predictions of the value of the subsequent quanta in accordance with the accepted hypothesis, as to the signal which is taking place, are elaborated.

At the moment when the real values of the signal cease to correspond to the predicted values the uncertainty of the situation increases and lasts until the probability of the new hypothesis increases to a sufficiently high level.

The reception of a complicated sound complex may be represented as a process of element-by-element consecutive analysis of the values of the signal which changes the initial probability of the hypothesis as to which complex stimulus is applied. Towards the end of the action of the complex the probability that we are dealing precisely with the given signal is very high. After passage of a number of empty quanta the probability of the hypothesis that this is an interval between complexes increases.

At the moment of time when the accepted hypothesis ceases to coincide with the real signal the uncertainty of the situation temporarily increases. The subsequent elements of the signal eliminate this uncertainty and lead to an increase in the probability of a new hypothesis corresponding to the real signal.

Thus, while the signal itself creates the uncertainty, it contains in itself the conditions for its elimination as a result of observing the value of this signal. The orienting reaction that arises is the mechanism which facilitates the collection and transmission of the information. The more complex the system of signals and the more closely related they are to each other in their signs, the more uncertain may the situation be and the longer it is necessary to observe the signal. The orienting reaction is correspondingly the stronger and longer, the greater the initial uncertainty and the more difficult it is to eliminate it in the course of observing the signal.

Let K_j be the "yes" sign at the moment of time j, and $\bar{K}_j$ the absence of this sign.

$P(K_j/A_i)$ is the probability of the sign K at the moment of time j in case of hypothesis A_i.

$P(A_i/K_j)$ is the *a posteriori* probability of the hypothesis after obtaining the data of sign K at the moment of time j. $P(A_i)$ is the *a priori* probability of hypothesis A_i.

The subject chooses one of the hypotheses $A_1\ A_2 \ldots A_n$, observing the appearance or absence of the sign at particular moments of time. On the basis of Bayes' theorem this process may be represented as a successive ascertainment of the probabilities of the hypotheses after observation of sign K at each of the subsequent moments of time

$$P(A_i/K_j) = \frac{P(A_i)\cdot P(K_j/A_i)}{P(K_j)}.$$

$P(K_j)$ is determined from the condition $\sum_1^n (PA_i/K_j) = 1$, because, according to the assumption, the hypotheses constitute a complete system of events.

The degree of uncertainty at each moment of time is determined by the entropy of distribution of the probabilities of the hypotheses

$$H(A_i/K_j) = P(A_1/K_j)\times\log_2 P(A_1K_j) + P(A_2/K_j)\times$$
$$\times \log_2 P(A_1/K_j) + \ldots P(A_n/K_j \log_2 P(A_n/K_j).$$

The orienting reaction arises when the uncertainty of the situation depending on the number of competing hypotheses reaches the threshold value of α.

$H(A_i/K_j) \geqslant \alpha$, where α is the threshold of "novelty".

The orienting reaction lasts until the uncertainty is eliminated and $H(A_i/K_j) < \alpha$.

Until the various elements of the signal eliminate the uncertainty the orienting reflex persists at a level depending on the entropy. $P_{op} = n[H(A_i/K_j) - \alpha]$, where P is the value of the orienting reaction, $H(A_i/K_j)$ —the entropy, α—the "novelty" threshold, and n —the coefficient.

Such is the scheme of the orienting reflex under the action of so-called indifferent stimuli.

The appearance of the orienting reaction in this case is determined by:

1) the value of the initial *a priori* probabilities of the hypotheses about the stimulus;

2) the evaluation of the *a priori* probabilities in accordance with the incoming values of the signal at various "quanta of time";

3) the elaboration of the prediction of the future value of the signal in accordance with the most probable hypothesis;

4) the value of the entropy at each moment of time, including the moment when the signal ceases to coincide with the elaborated prediction;

5) the threshold of the "novelty" of the stimulation.

In the process of repetition of the selfsame stimulus the extinction of the orienting reflex depends on the increase in the *a priori* probability of one of the hypotheses. As a result, the minimum number of elementary signals sufficing to eliminate the uncertainty decreases. This leads to a shortening and weakening of the orienting reaction.

In connection with the problem of elimination of hypothesis it is necessary to add the concept of "threshold of consideration of hypotheses". The hypothesis whose probability diminishes to less than b,($^-$), *i.e.*, $PA_i < b$ ceases to be considered.

In these schemes we proceeded from the concept that the orienting reaction persists as long as the situation is uncertain. However, it is possible to assume a scheme in which the orienting reaction is effectively included only at the moments of time which carry information. This can be traced against the background of a stably persisting orienting reaction when the system of hypotheses remains sufficiently constant. In the process of training the orienting reaction is transformed from a continuous reaction into a system of periodic "enquiries" concerning the properties of the signal. It is most expedient to make such "enquiries" at moments of time when the signal carries information. From a continuous strain of the attention the orienting reaction is transformed into a system of brief activations arising at the moments of time when the signal contains information. It may be assumed that each individual orienting reaction is the stronger the more information is anticipated at the given moment of time. In this case the agent of the orienting reflex is not the level of the entropy, but its change anticipated at the given moment of time. However, it is the entropy that is the main reason for maintaining the orienting reflex all the same. As soon as the uncertainty of the situation disappears the orienting reaction ceases.

An examination of the properties of such a selective

concentration of attention at definite moments of time may lead to the conclusion that it is a case of conditioned orienting reactions. The organisation of the orienting reaction as a system of "enquiries" at definite moments of time makes the mechanism of attention during tracing the stimulus more economical.

A comparison of such a scheme with real experiments confirms our foregoing inferences. Experiments show that orienting reactions persist the most stably at the moments of time which carry information, the value of the orienting reaction being proportional to the anticipated information. The precise moments of time at which the orienting reaction will be the strongest are determined by the system of hypotheses. In experiments with a conditioned motor reflex the orienting reaction also ceases when the entropy diminishes below a certain critical value, the latent period of the motor reaction being determined by the time during which it is necessary to receive information sufficient for the probability of one of the hypotheses to increase to the value needed to take a decision.

This time depends on: a) the total number of hypotheses, and b) the structure of the signal in time.

On the average with equiprobable hypotheses and equal probabilities of the signs $T = a + k \log_2 N$, where a is the time of a simple reaction, T is the time of a reaction to a complex stimulus, $k \log_2 N$ is the time of choice of one of the N hypotheses and k is a constant.

The experiment with a change in the system of hypothesis is critical for the theory being developed. With the change in the system of hypotheses orienting reactions at first extend over the entire duration of the signal and then arise only at the moments of time which are informative with regard to the new system of hypotheses.

Thus the orienting reactions depend on:

a) the appearance of an uncertainty under the influence of formulation of the task during a change in the situation;

b) the conditioned-reflex mechanism of maintaining the orienting reaction at definite moments of time which are informative with regard to the existing system of hypotheses.

In the beginning of elaboration of the conditioned reflex the orienting reaction is determined at each moment

of time by the entropy. After training, the orienting reaction is distributed in time in proportion to the information furnished by elementary signals at definite moments of time.

It is necessary to distinguish:

a) the maintenance of a high level of a potential possibility of an orienting reaction;

b) the realisation of the orienting reaction.

In the beginning of the experiment both forms of the reactions coincide. Then the readiness remains as long as there is uncertainty, but the orienting reaction concentrates at the moments of time which most effectively lead to elimination of uncertainty.

Thus the orienting reflex is a regulator which is switched on when uncertainty is created and which works in the direction of obtaining information that eliminates this uncertainty.

6. ALGORITHM OF THE ORIENTING REACTION IN TACTILE RECEPTION

When sound signals are used all elements of the stimuli are "compulsorily" introduced so that the active choice of the most informative moments of time is only a result of training. Nevertheless, in this scheme the internal activity reflected in the action potentials of the brain and the electrodermal reactions is timed to definite moments of information-carrying time. The same thing is observed when, instead of distinguishing sound sequences, the subject is asked to feel, with his eyes shut, convex points arranged in a row. Quickly going through the uninformative points the subject lingers on the informative points and, when sufficient information is received, reacts in accordance with identification of the object as per preliminary instruction, ignoring the remaining points which carry no information. The movement of the fingers along a chain of convex points is a reaction equivalent to following a line with the eye and distinguishing sound sequences. The lingering of the finger at definite points corresponds to intensification of the orienting reaction during reception of sound sequences. The process of palpation lasts until the uncertainty of the situation created by the instruction to distinguish presented unknown images is eliminated.

The system of informative points depends on the system of hypotheses.

Thus the movement of the finger in feeling may be regarded as a tactile component of the orienting reflex specially connected with the function of the hand as a cutaneous-motor analyser. However, such a "compulsory" tracing of the sequence of signals is only a specific case of the orienting reaction. Under conditions where the stimulus forms a spatial configuration there is a possibility for selectively fixing the hand or eyes on definite parts of the objects being distinguished. In such cases the orienting reaction is complicated by the fact that the organism actively chooses the elements of the stimulus which are necessary for identification of the image. From this point of view the orienting reaction ensures collection, reception and transmission of information. Since the study of the visual system, as a multichannel system, involves great difficulties it is advisable to examine the orienting reflex in the course of recognising, with the eyes shut, complex images (in letters) represented by a system of convex checkers.

In this case a separate checker is equivalent to a "quantum of time" for the sound sequence. The system of presented images is, as in the case of sound sequences, characterised by *a priori* probabilities. The movement of the finger is equivalent to oculomotor orienting reactions, the lingering of the finger—to intensification of the orienting reaction. The palpation of various points also alters the probability of the hypotheses, according to Bayes' theorem, and the experiments show that the subject ceases his search and calls the letter when the received information reaches the level that eliminates the uncertainty. The identification reaction time depends on the number of hypotheses being differentiated.

The model of the tactile component of the orienting reflex contains a possibility of an active spatial choice of the most informative points, which makes it possible to render the process of identifying the images more effective. The most informative points are those which make it possible to eliminate the greatest number of hypotheses, thereby increasing the probability of the remaining hypotheses to the utmost.

In cases of equal probability of the hypotheses such

points are those which make it possible each time to discard half the number of hypotheses, i.e., to dichotomise them.

In a general case the most informative points are those which yield the maximum of information.

With knowledge of the system of presented images and the probability of their realisation we can predict the most informative points at each step of palpation. This means that it is possible theoretically to calculate the most effective trajectories of palpation. Experiments with tactile differentiation of letters (L. Aran, Y. N. Sokolov, 1961) have shown good coincidence of a series of such theoretically calculated trajectories with experimentally obtained trajectories of palpation involving comparatively few hypotheses. In such cases the choice of each subsequent point of palpation, as concentration of the orienting reaction at definite moments of time during differentiation of sequences, depends on:

a) the initial system of representations;

b) the information received at the point palpated earlier.

The system of motor components of the orienting reaction is a chain reflex regulated by preceding information and directed toward the most effective reception of new information. Other components of the orienting reflex (activation of the brain, etc.) apparently ensure the most effective transmission and treatment of the information received.

The choice of the most informative points depends on the system of hypotheses with which the subject himself operates ("subjective system of hypotheses"). Contrariwise, by investigating the points chosen by the subject it is possible to infer the system of hypotheses with which the subject operates in the experiment. Let us examine, by way of example, the course of the tactile component of the orienting reflex in a case where the subject operates with letters shown in the picture containing 5×5 elements.

The experiment shows that the subject palpates the elements in the picture which carry the most information and ceases to palpate as soon as the information received has reached a value which makes it possible to infer the letter being perceived.

An analysis of experimental data on palpating letters

shows that the tonic orienting reaction persists until the situation contains uncertainty. Each "portion" of the information received presupposes a phasic orienting reaction. The orienting reaction ceases as soon as the entropy equals zero (the situation is completely determined). Phasic orienting reactions in the form of movements of the finger arise not in response to incoming "portions" of information, but are directed towards receiving it. Here, too, the leading factor is the uncertainty of the situation. Phasic orienting reactions are aimed at collecting information.

The connection between the entropy and the tonic orienting reflex also manifests itself in that the more complex the problem of differentiation and the greater the number of hypotheses with which the subject operates, the higher the level of the tonic orienting reaction and the stronger the phasic reactions. As soon as the situation ceases to be uncertain (when one of the hypotheses becomes the most probable) the orienting movements of the finger cease and a conditioned reaction arises—in this case the letter is called.

The algorithm of the tactile orienting reaction includes:

1) an evaluation of the initial entropy of the situation, which determines the level of the tonic reaction and the number of phasic components;

2) a singling out of the critical point, optimum with regard to the value of the information received in it; this is realised on the basis of the images recorded in the central nervous system;

3) a phasic reaction in the form of palpating the point and receiving the data contained in it about the elementary "yes" or "no" signal;

4) ascertainment of the *a priori* probabilities of the hypotheses on the basis of the signal received;

5) calculation of a new entropy and the value of the information received;

6) a repetition of 2, 3, 4 and 5 if $H > \alpha$. Cessation of the orienting reaction (identification of one of the hypotheses and realisation of the conditioned reaction) if $H < \alpha$.

The scheme of the orienting reflex must include:

a) a block of image records;

b) a block of calculation of *a priori* probabilities of images;

c) a block of calculation of *a posteriori* probabilities;
d) a block of calculation of the entropy;
e) a block of calculation of the position of informative points on the basis of determining the value of the information anticipated at the given point.

CONCLUSION

An analysis of the peculiarities of the orienting reflex leads to the conclusion that it is inseparably connected with the process of identification, perception. The more complex the process of perception, the stronger the orienting reaction. The probability description of the process of perception (Y. N. Sokolov, 1960) makes it possible to reveal the algorithm of the orienting reaction. While indicating the close connection between the orienting reflex and the process of perception, it is also necessary to note their differences.

To begin with, it is necessary to define the very concept of perception precisely. On the one hand, perception implies the activity required to create the image of the object, on the other hand—the image itself. If perception, as vigorous activity which is necessary to create the image of the object, coincides with the concept of orienting-exploratory activity, then perception, as the image of the object, is the result of this orienting activity. Thus the trajectory of palpation, as a system of orienting movements, does not predetermine the image which the subject will form. The origin of the image depends on the objective content, the information received at the points being palpated. The very same trajectory of palpation leads to formation of different images in accordance with the concrete information received at different points.

It follows that perception, as an image of the object, cannot be reduced to the system of orienting-exploratory reactions, although they are necessary in order to obtain the information from which this image is built.

It is also necessary to consider the influence of the system of hypotheses on the structure of the orienting reaction and the formation of the image. The assumption of a stable system of hypotheses—images retained in the memory—is a convenient abstraction. In reality the system of hypotheses, i.e., the system of images in the memory, is

reorganised in accordance with the objective content. However, until the system of hypotheses is reorganised, the subject describes new phenomena according to the old system of hypotheses. In this case identification of the object depends on the hypotheses with which the subject is operating. The errors of perception under the influence of dominating hypotheses correspond to illusions of apperception and effect of the set. But such illusions cease as soon as new objective content calls to life a new system of hypotheses commensurate with the objective content.

CONCERNING THE ACTIVITY OF MAN'S VISUAL SYSTEM

By A. N. LEONTYEV and Y. B. GIPPENREITER

1

The problem of perception is one of the main problems of psychology. This means that investigation of perception touches upon many of the most important psychological problems. On the other hand, the approach to perception and the methods of studying it are directly dependent on general psychological theories and change together with the latter. That is why the problem of perception is one to which the investigators always revert.

In the last decades Soviet psychological science has been devoting increasingly more attention to the concept of mental processes as a special form of activity of the same fundamental structure as any activity in general, including practical activity performed by external motor acts. It differs from the latter only in that, first, it performs a special function, namely, that of orienting the subject in the surrounding reality on the basis of its reflection in the brain or, as it is nowadays sometimes said, on the basis of construction of its model. This makes it possible to anticipate practical, "executive" acts, i.e., to put them into play, as it were, beforehand, to select the most adequate ones and to control them.

Secondly, it differs from direct practical activity in that it is characterised by a form of internal activity sometimes so concealed and reduced that it seems to assume the form of instant acts of purely spiritual judgement or understanding. And yet both structurally and in its origin internal mental activity is but a particular, even if very peculiar, form of human activity (16, 1, 18, 9).

This approach to mental processes, started in Soviet psychology by L. S. Vygotsky, also applies to the processes

of perception. The possibility and even necessity of such an approach to perception has particularly clearly come to the fore in our time when, under the influence of technical progress, the external motor executive part of many forms of labour activity has been reduced to few elementary acts and when the main load is carried by their "orienting" part, i.e., primarily the processes of perception—reception and treatment of information. If we may say so, labour activity has largely been transformed into perceptive activity; perception, which in manual or simple machine production represented merely a necessary condition and separate factors in the worker's activity, has now become a most complicated system of processes of search, detection, identification, watching, etc. It has become necessary to isolate and investigate not only the elementary psychophysiological functions which carry out these processes, but also the separate relatively independent perceptual *acts* performed by the worker and answering his different particular purposes, as well as the *operations* required to perform the given act under the given conditions.

It is precisely the approach in question that has determined, on the one hand, the general direction of our experimental studies of man's visual perception. On the other hand, our studies had been prepared by the development of the *reflex* conception of mental processes advanced by I. M. Sechenov and I. P. Pavlov (10, 11). According to this conception, all mental processes are, as Sechenov pointed out, reflexes in origin. This means that they all retain the complete structure of the reflex act, i.e., include in their composition both sensory (afferent) and motor (efferent) links, although the latter may in some measure or other be reduced. Introduction of the effector links into the composition of perception opposes in the concept of perception the reflex conception to the classical, "receptor" conception which attaches the main importance to the processes operating in the receptors; as for the effector links, they are for the most part regarded by it as performing the function of adaptation or as expressing the central processes which, although connected with perception, belong to another class of processes, as, for example, Helmholtz's "unconscious conclusions".

The view which regards processes of perception as

necessarily including the effector links fundamentally changes the conception of their general mechanism; the concept of receptors is elevated to that of *analysers* (Pavlov), while their mechanism as a whole is described as a complex multilevel functional system which incorporates numerous positive and negative feedbacks. The concept of a complex reflex functional system whose work physiologically underlies perception has served as another most important concept for our study. That is precisely why we have entitled our study a study of the *activity* of the visual *system*, emphasising the two concepts of "activity" and "system". The data furnished by the experimental studies conducted by us jointly with the workers of the Laboratory of Engineering Psychology, Department of Psychology of M. V. Lomonosov Moscow State University—N. Y. Vergiles, M. D. Gustyakov, M. N. Zaika, M. A. Kareva, L. Sedakova, V. A. Urazayeva, Y. G. Shirova and L. P. Shchedrovitsky (14, 2, 8, 12, 13)—have served as the material for the present work.

The main question we had to deal with was naturally that of the method of investigating the processes of visual perception commensurate with the aforesaid approach. We had to describe the content of the subject's activity aimed at solving the problems with which the subject is faced (we call such problems perceptive problems). As is well known, the visual receptor is a mobile organ capable of moving relative to the perceived object. Moreover, many authors, especially Sechenov, have long since held that in viewing objects the movements of the eyes are essentially analogous to the palpating movements of the hands (11). This point of view suggested the method of a detailed study of the motor activity of the eyes. However, any direct analogy between the palpating and visual movements is justified only under certain conditions, for example, in perception of objects with very large angular dimensions or under experimental conditions specially rendered difficult. The thing is that the eye is a multichannel "input device" which, as is well known, makes it possible to produce complex simultaneous effects, this circumstance suggesting the concept of a "screen" principle of producing a visual image. The extensive literature on the problem of studying the role and nature of eye movements, on the one hand, and the screen retinal effect, on the other hand,

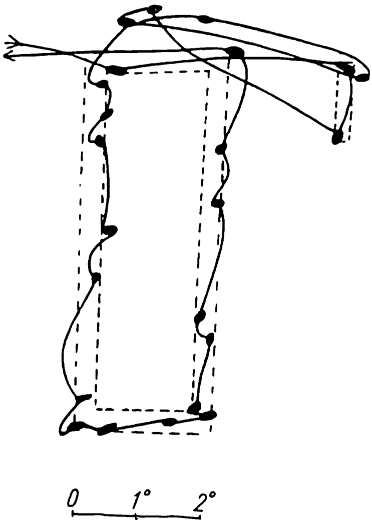
shows that the problems arising here are exceptionally complex and cannot be solved either by the "either ... or" or the "both ... and" principle (19). On the basis of a number of theoretical considerations we chose the way issuing from the study of the eye movements, aiming to analyse, on the basis of the facts obtained, the complex real work which is done by the visual system and which, in particular, creates effects of simultaneous perception.

As the initial technique we adopted that of recording the eye movements by means of a ray of light reflected from the eye and recorded on a photosensitive film. We used the sufficiently precise and reliable modification of this method suggested by A. L. Yarbus (17).

To begin with, we pursued the aim of describing the peculiarities of the eye's "behaviour" in solving various types of perceptual problems which we at first chose purely empirically.

In the first place we established the fact that eye movements are observed at macrointervals of time, whatever the visual problem, although their character and correlation with the spatial properties of the objects presented sharply change in accordance with the perceptual problem. Thus in cases of simple identification of objects ("look and tell what is in the picture") the eye movements are not in external conformity with the geometry of the objects, which, incidentally, is a well-known fact. It is a different matter when the subject is asked not merely to identify the object, but, for example, to compare the dimensions of its different elements with each other, to distinguish their spatial correlations, their number, etc. The solution of visual problems of this vast class necessarily causes, as experiments have shown, macromovements of the eyes correlated with those properties of the objects, which the subject must "see", i.e., distinguish. A sample of the record of the eye movements made during the solution of a visual problem of this class is shown in Fig. 1. In this case the problem was to correlate the length of a part of a straight line shown on the right with the perimeter of a rectangle. As the record of the movements shows, the subject's eye first moves along the portion of the straight line, as though measuring it, and then along the rectangle, reproducing its entire countour.

Fig. 1. Record of the eye movements of subject solving the problem of how many times the given length will go into the perimeter of a rectangle



Particularly important is the fact that the afore-described character of eye movements during the solution of such problems is also retained in cases where the angular magnitude of the objects does not exceed 1.8° (2). This fact shows that the aforesaid movements are not mere shifting, but perform some special function.

An examination of a considerable number of records made of the eye movements compared with the character of the presented objects and the problems assigned to the subjects by the instructions confirms the fact that the eye movements change primarily in accordance with the problem, thereby revealing their connection with the structure of the perceptual activity. This does not mean, however, that the eye movements directly express this structure and only this structure. As we shall see below, the eye movements are connected with processes at various levels, perform various functions and express, as it were, the general resultant of the processes superposed upon each other and as a whole forming the work of the visual system.

As a matter of fact, this preliminary conclusion made it possible to ascertain the problem of our study: by continuing to study the eye movements under conditions of systematically changing problems to give, as it were, their layer-by-layer analysis.

Such an analysis had to reveal the structure of the activity which is carried out by the visual system and make it possible to describe the specific sensory processes forming part of this structure, as well as the "secondarily

sensory" processes, as processes operating at the level of external eye movements and at an internal, "interiorised" level.

2

Digressing from the real succession of our studies we shall first describe the series of experiments devoted to the organisation and function of the shifting (transport) eye movements. The method of these experiments was as follows:

Before the subject there was a square screen visible at an 80° angle. In the centre of the screen there was a point of fixation. The screen was equipped with a device which made it possible to blot out objects with the form of an angle, its vertex pointing in one of 4 directions: up, down, left, right. These objects were 10°, 20°, 30° and 40° away from the centre of fixation and were presented at random. According to the instruction the subject had to react to the appearance of an object by moving the handle of a four-pole switch in accordance with the direction of the angle vertex. The recording apparatus made it possible to record the eye movements and measure the following time intervals: the time of the motor reaction—from the presentation of the object to the beginning of the switch movement; the latent period of the eye movement—from the presentation of the object to the beginning of the jump in the direction of the object; the duration of the jump; the time of choice—from the moment the eye reached the object to the beginning of the hand movement. The time was measured with electronic time meters and temporal scanning of the jump on a cathode-ray tube. The electronic time meter which marked the beginning of the jump was switched on by the bioelectric impulse produced by the eye movement.

As the experiments have shown, the appearance of an object in the field of the subject's vision necessarily caused the eye to jump at the object. The latent period of the jump of the eye averaged 250 msec.; the motor reaction of the choice (movement of the switch) occurred *after* completion of the jump at an interval which varied with the subjects.

To reveal the nature of such a lag of the reaction, the conditions of the experiments were altered as follows: the

subject was now required to respond to the appearance of an object by moving the switch regardless of the direction of the vertex of the angle. In other words, in the second series the experiment was conducted according to the scheme of a simple motor reaction. The result was that under these conditions the reaction time of the hand almost coincided with the latent period of the jump of the eye. Thus this series has shown that for a *simple* motor reaction to the appearance of an object in the field of vision a preliminary jump of the eye at the object is not necessary.

The facts furnished by the afore-described series warrant certain preliminary conclusions which, as we think, are of fundamental importance in characterising certain peculiarities of the work of the visual system as a whole.

The jumping movements which ensure the set of central vision *are necessary* only in the structure of the activity which requires identification, i.e., proper perception of the object, whereas in cases where formation of a precise image of the object is not necessary and the reaction occurs in response to the appearance of any object of a given class it may be initiated by signals from the retina without visible participation of oculomotor operations.

It is also necessary to take particular note of the fact that two functions of the retina are clearly observed in the afore-described experiments: on the one hand, the function of reception of visual signals, which controls the extrasystemic motor processes on the elementary sensory level (trigger stimuli with formation of the image proper) and, on the other hand, the function of interosystemic afferentation, i.e., afferentation of the motor processes of the visual system itself, in this case the simplest jumping eye movements.

We managed to trace the work of the visual system on higher levels in experiments studying specialised eye movements, on the one hand, and in experiments on various aspects of perception of intricate visual complexes, on the other hand.

In the experiments conducted in the first direction we reversed the correlation between the sensory proper (afferent) and motor (efferent) links of the visual system. In the afore-described first series of experiments the eye movements ensured the set of central vision for the object

and thus served the system's subsequent work of identification, whereas now it had to assume the main function. Contrariwise, the sensory link had to perform primarily the function of service and of an indicator of the correctness of the performed movements.

This type of problems made it possible to exclude the extrasystemic motor reactions and to begin studying the visual system at a new level, a level where its motor work, isolated from the external motor adaptational acts, is a relatively independent activity. At this level, the work of the visual system is now performed in its full composition including the performance of purposive perceptual acts and mastered, reduced operations. The simplest problem which answered the aforesaid purposes and which we chose was the problem of visually tracking an assigned line among other lines.

The experiments were conducted by the following method: A rectangular object with parallel lines drawn on it was placed before the subject; the intervals between the lines equalled the width of the lines. The total angular size of the object was 20°, the density, i.e., distance between the lines (as also their width) was varied from 10 to 60 ang. min., the beginning of one of the lines was marked by means of a dotted light signal. The subject had to track the marked line visually and point out its opposite end; the marking signal was switched off at the moment the subject began working. At the end of tracking the subject switched on the second marking signal indicating the end of the assigned line, which enabled him to appraise the precision of the tracking—the arrival of the eye at the end of the assigned line or, in case of an error, at the end of one of the adjacent lines. During the experiment the subject's eye movements were recorded.

The results of these experiments have shown that with certain values of the object's density (40-60′) the subject solves the line-tracking problem unerringly; with greater density values the subject begins to err, the number of errors sharply increasing at a density of 10-20′. The records of the eye movements show that under the aforesaid conditions the tracking operation is performed by eye movements consisting of a series of macrojumps and fixations. In cases of an unerring solution of the problem all points of fixations fall on the tracked line, but, if at

some moment the eye movements shift to one of the adjacent lines, the subsequent tracking shifts to this line and gives rise to an error. Since the lines are visually similar no visual control was possible in the tracking process; it was included only when the tracking ended, i.e., when the second marking signal was switched on, and served only to appraise the correctness of the solution of the problem.

The second variant of this method consisted in the fact that a uniform object consisting of parallel lines was replaced by a uniform object consisting of small diameter circles ("dots") which changed in density within the same limits. The second difference of this variant was that the subject now had to retain the point marked in the beginning of the experiment by a short signal; the errors were correspondingly expressed in a loss of the assigned point and the shift of the eyes to one of the adjacent points. To appraise the precision of fixation, the subject had to press a button at the end of it, and a light signal designating the assigned point went on again. By the lighted point the subject determined the direction and extent of the shift of his eyes, the point surrounding the assigned point serving as a "reading scale". Thus in the experiments under consideration individual elements (points) of a uniform plural object served simultaneously as objects of visual action, "interferences" and a reading scale.

As in the afore-described experiments, the appearance of errors depended on the degree of the object's density, and most of the errors were made with the same density values—10-20 ang. min.

The analysis of the record of eye movements made on a moving photofilm shows that during the fixation of the point the eye is in continuous motion in which drifts and jumps are clearly observed. The record shows that the drifts tend to lead the eyes away, while the jumps are rapid corrective movements which return the eye in the direction of the initial position. These two types of movements ensure the keeping of the eye in a field constituting an average of 14 ang. min. The record presented here (Fig. 2a) shows that during the movement the eye goes beyond the adjacent points. The record presented in Fig. 2b shows the site of origin of an error connected with a drifting "slipping down" of the eye, which was not adequately corrected by the jumps.

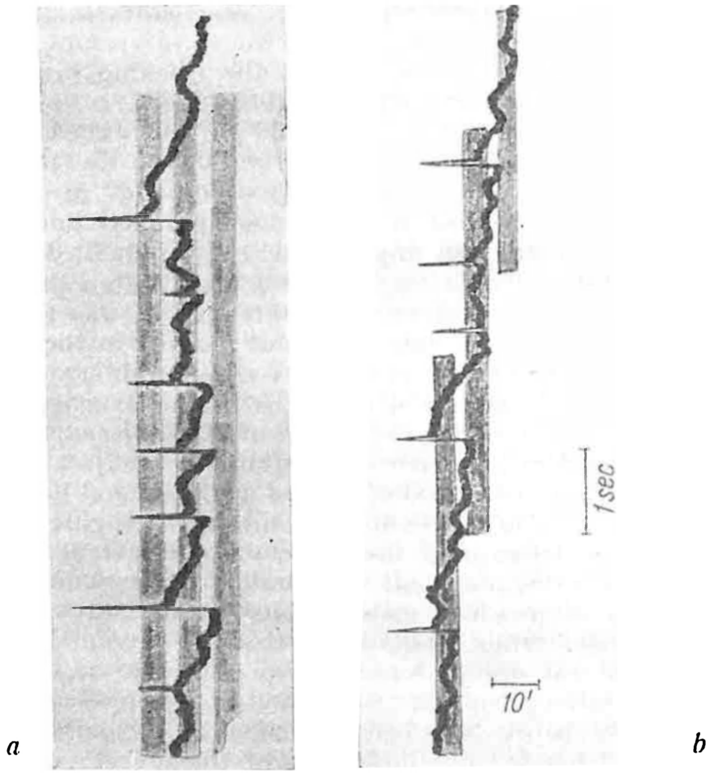


Fig. 2. Record of the eye movements (horizontal component) during fixation of individual dots of a dotted object:
a—unerring fixation; *b*—fixation with an error of 2 dots to the right

It should be noted that, according to the records of the eye movements and the verbal report of the subjects, the direction and value of the fixation error coincided. Thus, if the subject discovered after de-excitation of the marking point that his eyes had shifted one point to the left of the assigned point, the record also showed the eyes to be shifted the same distance and to the same side.

The two variants of the method using plural uniform objects made it possible more fully to reveal the correlation between the sensory and motor components in the work of the visual system.

It will be remembered that one of the main results produced by the aforesaid experiments was the fact of regular occurrence of errors, of "loss" of the point (or line) with objects of certain densities. To analyse this fact, it is expedient to use the concept of "*gaze*" as a set of vision differing from the set of the *eye*. Whereas the former set is, as it were, an internal, functional direction of vision, the latter is the position of the eye relative to the object characterised by the direction of the visual axis. Although in the foregoing experiments, as most commonly also under natural conditions, the line of gaze coincides with the visual axis (which is the reason for their frequent identification), a microanalysis always reveals a certain discoordination between the gaze stably directed toward a fixed point and the visual axis which continuously alters its direction because of the involuntary movements of the eyes. Thus the gaze is a resultant of the eye movements, under certain conditions manifesting an "insensitivity" to these movements.

An important factor characterising the dynamics of the gaze in time is its periodic *interruption* which is due at least to two causes: winking and saccadic movements (voluntary or involuntary) which accompany the fixation or tracking. During winking vision is interrupted and during a jump it is greatly impaired (15). That is why we may take it that as a result of an interruption the gaze "loses" the assigned point and during restoration is directed toward another point indistinguishable from it.

The erroneous sets of the eye for another point occurring as a result of winking (or jump) may be explained on the basis of the concept of the eye as a tracking system with a double regulation—visual and proprioceptive (6, 7). After an interruption of the gaze caused by a jump or winking the fixation mechanism cannot resume its action on the basis of visual afferentation since in view of a complete uniformity of its elements the object carries no visual information as to which is the assigned point. As a result the set of the eye is established only on the basis of proprioceptive signals from the eye muscles which have retained a "memory" about the position of the eye prior to the interruption. However, the set of the gaze may be established only within the limits of a certain threshold

zone (14). In cases of high density of the object several points directly surrounding the assigned point turn out to be in this zone and the gaze comes with equal probability "to rest" on any of them.

Thus the size of the zone within which the errors of fixation occurred in our experiments is a value characterising the precision of proprioceptive sensitivity of the oculomotor apparatus which participates in the mechanism of fixation. By analogy with the "insensitivity" zone of the retina (5) we have here another "insensitivity zone" which characterises the refractive power of proprioception of the eye muscles. According to our experiments, the size of this zone is 40′ along the radius.

The aforesaid is also applicable to the results of the experiments with tracking the line of a uniform hatched object, but with one additional remark. According to the records of the eye movements, the tracking is effected by a number of voluntary jumps with intermediate fixations. It follows that in addition to the aforementioned causes of the interruption of the gaze, namely, winking and involuntary jumps, there was one more cause—voluntary saccadic eye movements.

In the light of the foregoing considerations we can explain, in particular, the increase in the errors of fixation and tracking upon increase in the density of the objects. It is due to an increase in the number of interferences (adjacent points and hatches) in the zone of "proprioceptive insensitivity" and in connection with this to the increased probability of the gaze shifting to them.

Hence, the process as a whole, which we observed in our experiments, may be described as follows:

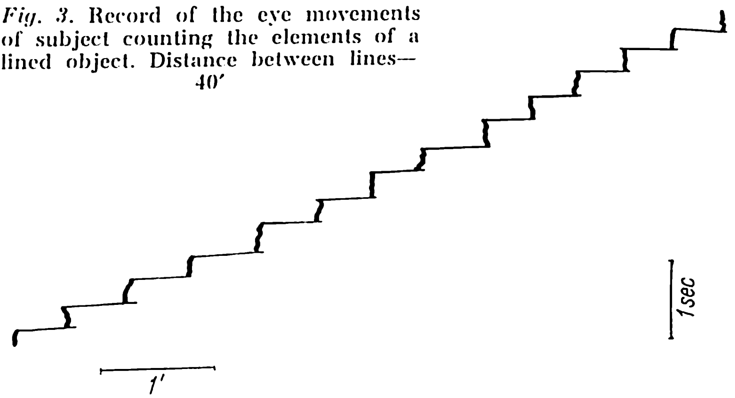
It is characterised by the fact that it satisfies the requirements of the specially perceptual, visual problem: it is necessary *to see* where the line ends or *continue to see* the marked point. However, this perceptual problem is solved by means of motor operations. When the gaze tracks a line the eye effects a number of voluntary jumps in the assigned direction and must be able to do it. In case of fixation of the point the voluntary activity of the eye is expressed in the use of the mechanism of corrective jumps to control the involuntary drifting of the eye. In view of the uniformity of the object the effectiveness of these processes, i.e., the degree of success in solving the

perceptual problem depends primarily on the work of the muscular apparatus—the precision of proprioceptive control and muscular proprioceptive memory.

Subsequently, while developing the same methodological line of eliminating the current afferentation of the process on the part of the retina by the conditions of the experiment, we tried to conduct experiments with problems which, while preserving the leading role for the motor link, would at the same time be of a more object character. The latter enabled us to isolate in greater relief the composition of the investigated process as an activity in the true sense of the word.

An object consisting of 20-30 vertical hatches was placed before the subject who had to count them, according to the instruction, one by one from the left to the right. The records of the eye movements (1) show that this problem was solved by a series of successive similar eye movements. The same phenomenon was observed as in the aforementioned experiments, namely, appearance of errors with critical values of object density. That was to be expected since, in counting, both the afore-described forms of eye movements take place under conditions of action

Fig. 3. Record of the eye movements of subject counting the elements of a lined object. Distance between lines—40′



with a uniform plural object: fixation (alternately on each hatch) and tracking (jumps from hatch to hatch). We are citing these experiments because they show with emphatic clarity, first, that the visual system is exerting here certain purposive *action*, namely, the action of counting the objects, and, secondly, that this action is exerted by the

operation of "counting one-by-one" which is characteristic of it. What strikes the eye in this case is that this operation is identical with the method used in counting objects with a finger. There can be no doubt that this operation, like the aforementioned operation of measuring off the perimeter of a figure, is formed first of all precisely as an external motor manual operation and is then transmitted to the visual system which "learns" to perform operations of this kind. The transmission of operations to the level of the visual system is a transition to their more interiorised forms, since eye movements are no longer effected in direct contact with objects and are detected only by instrumental observation. Particularly remarkable is the fact that the operations which the eye learns from the hand are of a socio-historical origin, i.e., are a product of the development of human culture. The eye thus appears to carry out specifically human and at the same time theoretical activity.

3

We started our analysis by studying the motor activity of the eye. Now we are faced with the problem of describing the activity of the visual system from the point of view of perception proper. To do this we have to set forth the experiments in which the work of the visual system seems to go beyond the level of external oculomotor processes and creates the effect of instant perception.

We succeeded in obtaining this effect of instant "discernment" already in the experiments with line tracking. The fact is that when the lines drawn on the object were gradually shortened (while all other parameters of the object were retained) there came a moment when the subject, together with the appearance of the signal assigning the line for tracking, at once saw its end, the size of the field of such instant perception of the whole line being dependent on the density of the object—the greater the density, the smaller the field. Thus with a density of 5 ang. min. the size of the field was 1-2°, with a density of 20 ang. min.—10°, etc.

As the records of the movements show, in these experiments the eye makes but one jump—from the beginning of the line right to its end. An impression is thus created

that the effect of instant grasping is confined to certain mobile limits which regularly depend on the properties of the object and within which the eye shifts in one jump. We call this mobile field the *afferentation field*. The functional characteristic of this field consists in the fact that the instant retinal afferentation of the motor intero-systemic processes (and, as we saw earlier, also the extrasystemic movements) already described by us takes place within its limits. Its maximum size may under certain conditions reach the size of the total field of vision, while its minimum size may be 1°.

Thus what we call the afferentation field is a spatial expression of the function of retinal afferentation which serves the process of setting the eye independent of the arising perceptual end effect. The latter must be emphasised because, in addition to the afferentation field, one more zone comes experimentally to the fore; this zone, which we have named the "operative field", characterises the spatial limits of the possibility of obtaining visual information under conditions of one fixation, i.e., with an unshifting eye.

For example, if the subject is asked to find the assigned number among other numbers and to arrange the numbers according to groups, as shown in Fig. 4a, the subject's eye does not stop on each number, but confines itself to

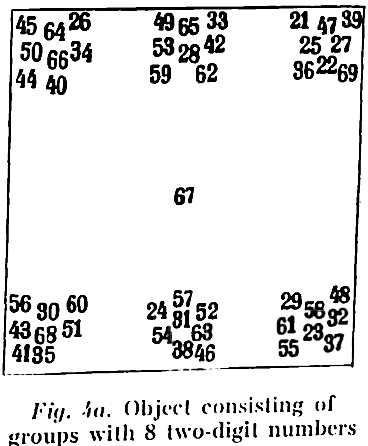


Fig. 4a. Object consisting of groups with 8 two-digit numbers in each group

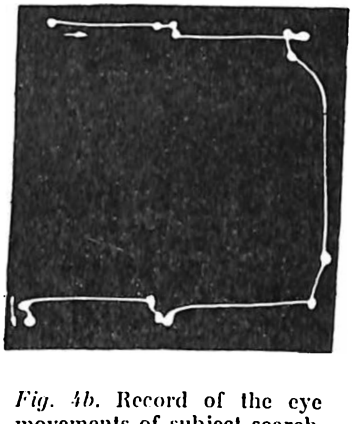


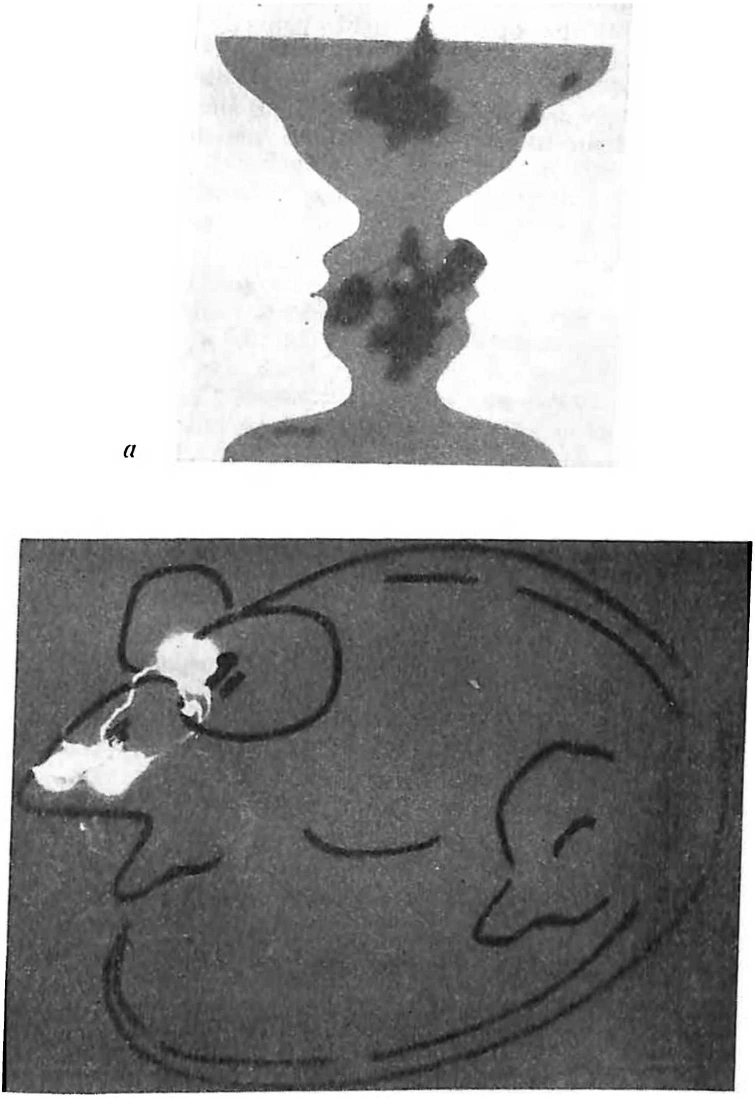
Fig. 4b. Record of the eye movements of subject searching for No. 35 in the given object

2-3 fixations on a group of 8 numbers (Fig. 4b). In this case the work contains no errors. Thus one fixation makes it possible to identify several objects located in a certain area. The phenomenon of the operative field comes still more clearly to the fore in the experiments with perception of double ("turning-over") images. If the subject's eye movements are recorded when he is instructed to try to see the images alternately, the eye is observed to limit itself to changes only in its general position with respect to the object, i.e., to select for each aspect of the image its point of fixation (Fig. 5a, b). These facts are the more convincing since the given conditions exclude the possibility of identification, so to speak, by guesswork, by individual, inadequate elements, which may take place in identifying ordinary single figures, and the process of perception is accompanied by a clear subjective effect of seeing the entire image as a whole.

According to experimental data, the operative field is narrower than the field of retinal afferentation. At the same time it is not conditioned by the peculiarities of retinal morphology. Both these propositions may be demonstrated in experiments with special test objects. Aiming to exclude the factor of unevenness of the refractive power of the retina, i.e., its diminution from the centre to the periphery, we constructed a test object as follows: the object contained radially-arranged rows of letters; the letters increased in size from the centre to the periphery in proportion to the diminution in visual acuity in corresponding directions. Thus with the fixation of the central letter of the object the diminution in visual acuity was practically completely compensated for.

In the experiments with such objects the subject had to call the letters he perceived on the condition of strict fixation of the object. Compliance with the latter requirement was controlled by a record of the eye movements.

As the experiments showed, under these conditions the letters could be identified within the limits of 15-20° along the radius (Fig. 6); the letters outside this region were not identified by the subjects. At the same time, as the experiments with the additional instruction showed, the subjects' eyes could jump to the extreme letters of the object (at a distance of 30° from the centre), i.e., these letters could perform the function of afferentation.



a

b

Fig. 5. Record of the eye movements of subject alternately seeing each of the double images:
a — vase — profiles; *b* — rat — man's profile

Thus these experiments clearly revealted the disparity between the dimensions of the afferentation field and the operative field: the operative field proved to be much narrower than the afferentation field.

The second fact, the significance of which we shall discuss below, was that beyond this field of identification there showed an intermediate zone in which the subject

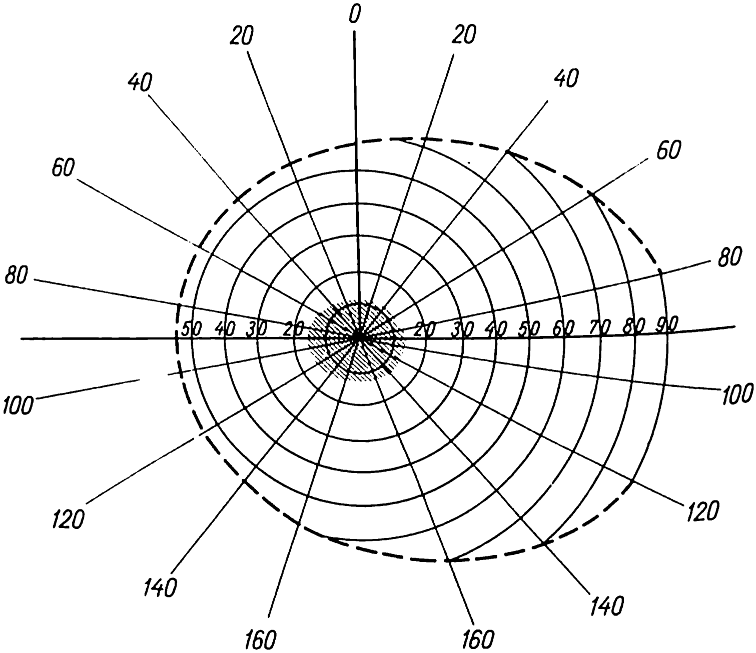


Fig. 6. Field of vision corresponding to 75 per cent of correct identification of letters in a radial table (for sizes of letters=3 threshold units)—hatched. Total field of vision—dotted

could see some elements of the letters without identifying the letters.

The dimensions of the operative field, like the dimensions of the afferentation field, are dynamic. Thus the values obtained in the experiments with a compensating object just described express its maximum dimensions, whereas in the experiments without a forced fixation of the eye its size decreases and at the same time reveals characteristic dependences upon a number of factors. For example, in the aforementioned experiments with the

search for numbers in groups, about 3 numbers were perceived in one fixation in a group of 8 numbers; but, if the numbers were evenly scattered over the entire table, the perception of each number required a separate fixation. Thus the division of the object is accompanied by a narrowing of the operative field. This does not mean, however, that the value of the operative field is a simple function of the degree of grouping of the objects. For example, if the groups are increased from 8 to 12 numbers each, the perceived numbers again diminish to 1.5 in one fixation, although the mean fixation time remains the same—about 250 msec.

We cited the foregoing data with the aim of emphasising that, although we use the spatial term "field", we do not connect it with any morphological constants (as it is done in regard to the concept of the central or total field of vision); nor do we associate it with the geometrical conception proper. In this sense the "field" is for us not a "window", but a spatial expression of a definite function of the visual system.

4

The study of perception under conditions of a shifting eye raises a most important and difficult problem. This problem arises, as it were, at the crossing of two kinds of facts. On the one hand, these are facts which at first sight attest the possibility of instant and passive identification of objects, at least within certain spatial limits or perhaps wihin the limits of a certain volume of information. On the other hand, it is a whole system of facts which denotes an internal connection of such "simultaneous" effects with a successive character of work of the visual system as a whole. The very experiments with the radial compensating table suggest that the process of identification of objects located on the periphery of the operative field is gradual, alternate and requires rather considerable time, about a few seconds. Still more significant is the phenomenon which consists in the fact that, despite the instruction, the subject's eye performs in the zone of fixation movements which assume the character of "heaves", i.e., as it were, inhibited, reduced jumps reaching 2° in amplitude (Fig. 7). It may be assumed that

these reduced eye movements are associated with the internal successive work done by the visual system in order to identify objects within the operative field. These reduced eye movements are comparable in their implication, for example, to the movements of the organs of articulation during internal speech.

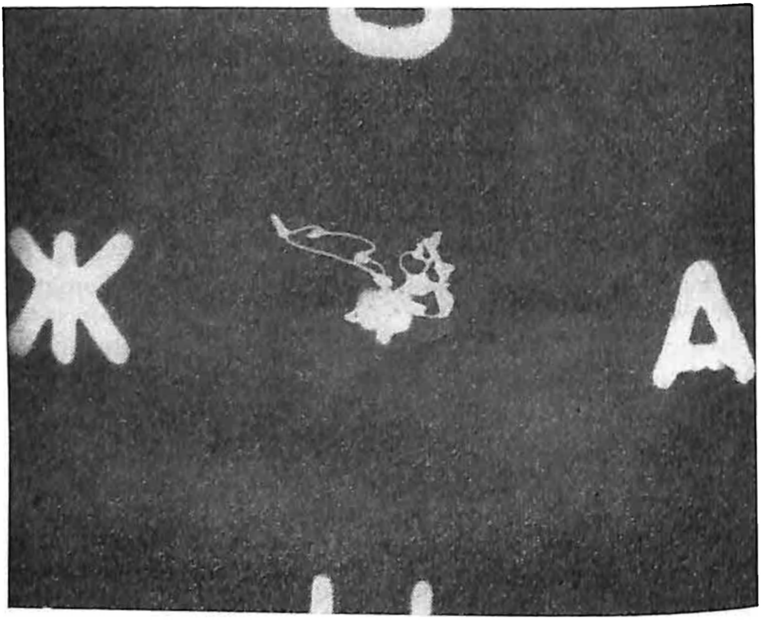


Fig. 7. Record of the eye movements of subject instructed to fix the central letter in the table and, if possible, call all the other letters

From the point of view of the concept under consideration the phenomenon of identification of objects with a relatively immobile eye reveals one more level of interiorisation of the processes in the visual system. Now these processes assume the form, as it were, of movement of attention. The reduced external "heave"-type activity of the eye expresses fading of the processes of transition of the attention from one element of an object to another.

The foregoing but very incompletely describes the dynamics of the system at the interiorised level. To gain a deeper insight into it, we shall have to introduce a few

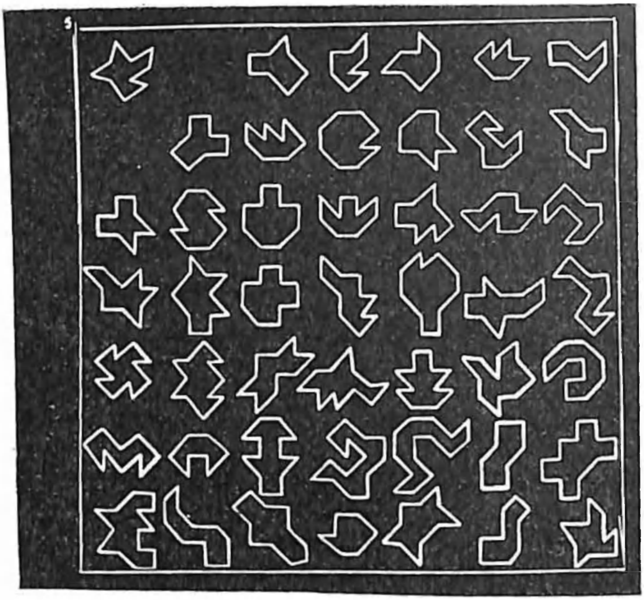
more facts and concepts, for which purpose we shall describe the experiments of one of the subsequent series.

The subject was given a table containing unfamiliar geometrical figures. In the upper left corner there was a figure that served as a model (standard). In accordance with this model the subject had to find an identical figure in the table. The various figures in the table differed from the standard and in accordance with their differences formed several classes. The subject's eye movements were recorded. How did the subject's activity manifest itself under these conditions?

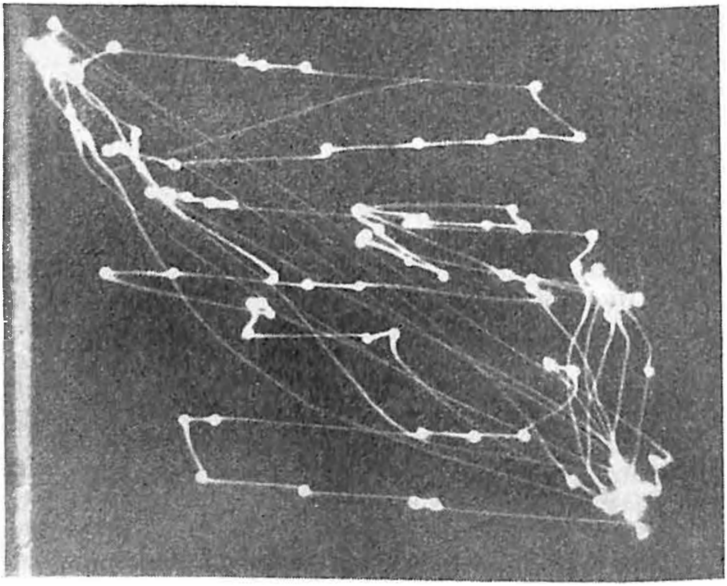
After a preliminary acquaintance with the standard the subject examined the table. When the eye fell on certain figures it made a jump which returned it to the standard, whereas in the case of other figures no such return movements to the standard were observed (Fig. 8a, b). An analysis shows that the figures which return the eye differ from those from which the eye does not return to the standard by different degrees of likeness to the standard. The former belong to the class closely resembling the standard, the latter—to classes bearing less resemblance to it. Thus the experiments have shown, firstly, that while the subject may at any moment look at the standard, he does not memorise it precisely and this in its turn accounts for the return movements which are necessary to compare the figures with the model, and, secondly, that such return movements occur only in cases of some figures, which means that even before the comparison the figures are divided into those about which there arises a hypothesis of their possible coincidence with the model and those about which this hypothesis does not arise. In other words, before identification the subject receives certain pre-information and guiding himself by it begins actually to identify the figure, i.e., to verify the hypothesis of coincidence of the figure with the model.

An example of such work of comparing the figure with the standard is shown in Fig. 9a, b.

Thus the data furnished by these experiments, like other data of similar import, necessitate the introduction of the concept of one more function of the visual system, namely, the function of pre-information and, correspondingly, the concept of a "pre-information field". As we have already noted, the dimensions of the pre-information field are, as

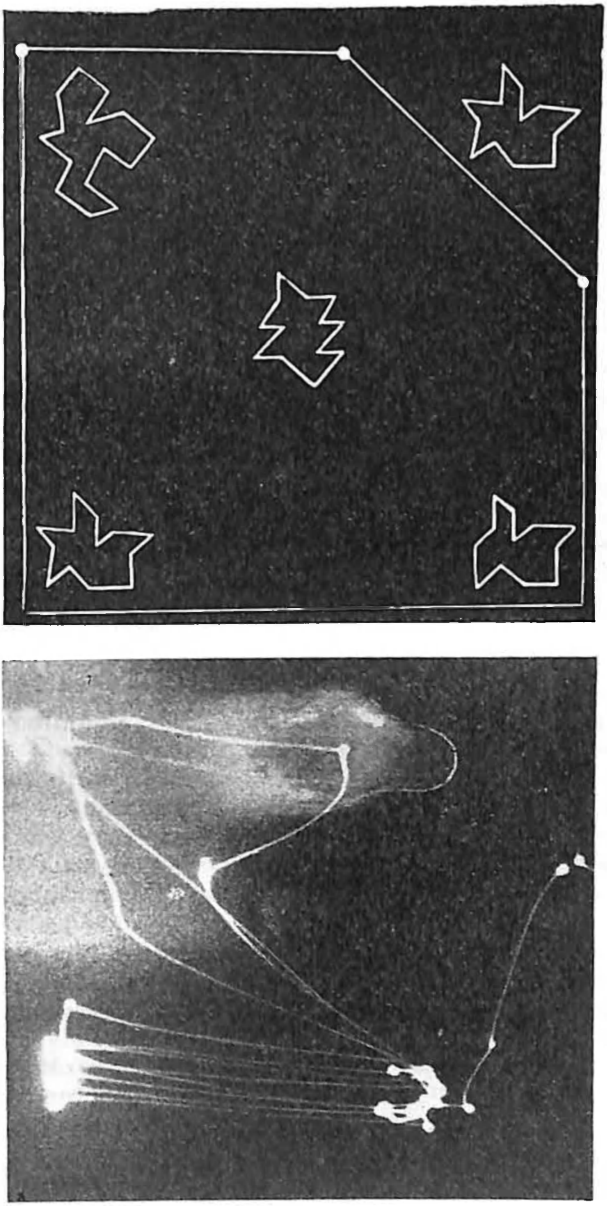


a



b

Fig. 8. a—Object consisting of 46 irregular geometrical figures. Standard in upper left corner. Size of the whole object—14°;
b—Record of the eye movements of subject trying to find in the object the figure identical with the standard



a

b

Fig. 9. a—Object consisting of 4 irregular geometrical figures. Standard in upper left corner. Size of the whole object—14°; *b*—Record of the eye movements of subject trying to find in the object a figure identical with the standard (record shows careful work of the eyes endeavouring to establish resemblance of one of the figures to the standard)

it were, intermediate between those of the afferentation and operative fields which correspond to the function of receiving complete information. This is also evident from the records of the latter, just described experiments. While working in the regimen of a pre-information search the eye makes no more than one fixation per figure and in some cases limits itself to one fixation on a group of figures which sharply differ from the standard. At the same time the work in the regimen of identification, i.e., reception of complete information, is characterised by repeated fixations on the object, which is attested by much smaller dimensions of the operative field which in this case accommodates but part of the figure.

The methodological course we pursued in the foregoing experiments consisted in exteriorising and thereby making accessible to observation the process which under other conditions may be interiorised. This was achieved by the fact that the standard was not put in the bloc of the visual system's memory, but was given in an external object form so that the problem of choosing from many figures scattered over a wide field was solved by means of external eye movements. However, the picture changes essentially when the standard, which is a necessary condition of any identification, is internal, retained in the memory.

Now the process of verification of the hypotheses seems to change its direction. It moves not in the object-external-standard space, but in the object-engram space, the engram retained in the bloc of the visual system's memory; but the latter is no longer a space of the external field of vision. Thus the interiorisation of the standard necessarily involves an interiorisation of the process.

Does this mean, however, that the process now assumes a strictly instant character? Although widespread views resting on phenomena of tachistoscopic perception capable of furnishing complete information about an object insist on a strict instantaneousness of identification, special experiments do not confirm it. It is apparently necessary to distinguish two questions: the question of the possibility of identification under conditions of instantaneous *presentation* of an object and the question of instantaneousness of the *identification itself*. On the basis of the distinction between these questions the following experiments were conducted in our laboratory:

An object was presented to the subject by means of a projection tachistoscope. The exposition time was limited to 100 msec. The presented objects consisted of 8 signs (letters, numerals) located in groups of 4 on the right and left of the fixation point; the signs in each group were arranged in the form of a square. The distance from the fixation point to the centre of the group was 5°, the size of one sign was 1°. The total horizontal size of the object (distance between the extreme elements) was 12°. The subject had to identify as many of the signs presented as possible. The eye movements were recorded all through the experiment, the marks indicating the moments of exposition and the beginning and end of the subject's verbal report. We were thus able to obtain a picture of the eye's behaviour during the period directly preceding the exposition, at the moment of the exposition and after the end of the exposition ("postexposition movements").

These experiments produced the following results. Before the beginning of the exposition the eye usually remained in the zone of the fixation point. During the exposition which was shorter than the latent period of the jump of the eye the record, naturally, failed to detect any specific changes. It was a different matter with the behaviour of the eyes during the postexposition period. Immediately after the end of the exposition the eye made a jump in the direction of one of the signs (most commonly to the left and upward), which was followed by a series of further shifting movements that continued during the period of the subject's verbal report. Only after the report did the subject's eye stably return to the fixation point, although it was lighted all through the postexposition period. The very fact of necessarily appearing postexposition movements warrants the assumption that they express a special activity of the visual system connected with identification of objects. The conditions of tachistoscopic presentation only spread in time the volley of the initial retinal afferentation and the identification activity proper. This assumption is attested by a number of facts. Firstly, as the experiments show, the report of what was seen always begins from the part of the object in the direction of which the first postexposition jump of the eye was made. Precisely this part of the object was reproduced, and with the greatest precision at that. Secondly, the ana-

lysis shows that the field of the eye's postmovements reproduces the location of the object's elements. For example, the postexposition movements in the work with the afore-described object arranged themselves within the limits of a horizontally elongated rectangle. But when we started the experiments with objects in which the signs were arranged in the form of a square with a fixation point in its centre the eye moved within the limits of the square field.

It is important to note that the scope of the postexposition movements is much smaller than the size of the object. Thus with the object's total horizontal size of 12° the scope of the horizontal movements was within 5°. This factor warrants the discussion of the question of the possible significance of the postexposition movements of the eyes. They are apparently related to the movements observed in the experiments with artificial fixation of the centre of a multielement object. In other words, they may be conceived as an external motor expression of some internal temporal process in the visual system.

Since the solution of the problem of identification of objects had a speech outlet in our experiments and the postexposition eye movements largely coincided in time with the verbal report, the possibility of interpreting them as movements connected with external speech reactions was not excluded. In view of this we conducted additional control experiments. They were characterised by the fact that the subject began his report on the perceived elements of the object only on the experimenter's signal which was given 10 seconds after the exposition. The experiments have shown that during these 10 seconds the postexposition eye movements are fully retained, while the transition to the verbal report leads to a diminution in their amplitude and number. Thus the postexposition eye movements exhibit no positive connection with external speech processes. However, this does not at all mean that the postexposition activity of the visual system is in no way connected with speech activity. On the contrary, the aggregate of facts concerning the regulatory role of speech and, in the first place, the fact that verbal designation of an object is a necessary condition of the categoricalness of its perception speak in favour of such connection. Moreover, the process of verbal designation in identification is

rightly conceived not as a special process of subsequent treatment of its product by thinking and severed from perception, but as a process incorporated in the activity of perception itself.

In the terms adopted by us we can speak in this case of the speech-level work of the visual system since identification, i.e., perception proper of the object, necessarily requires correlation of the received pre-information with the standard which man retains in generalising systems based on language. Such standards are not only addresses of the incoming pre-information; they also perform the function of controlling the processes of identification.

As the experiments show, the control of identification of complex objects by the standard retained in the memory bloc of the system is exercised so that the process is, as it were, quanted, i.e., operates in an element-by-element manner, the value of the elements ("portions") and correspondingly their number per object depending on the properties of the available standards. For example, in identifying the signs of a letter alphabet mastered by the subject a letter is the elementary portion of the treated pre-information. But, if the subject is identifying signs of an unfamiliar alphabet, their identification takes place according to fractional elements of the sign. On the contrary, in cases of short presentations of whole words not all, but only some letters of the word are identified by the action of the probability mechanism.

It is precisely this element-by-element character of the identification process that the postexposition macromovements of the eyes recorded by us express. As for the motor expression of the successive "object-internal standard-object" process, this process is not expressed. It is possible, however, that a fine study of the micromovements will enable us to "read" also this process. Now, although we have an appropriate method at our disposal (3) we are not as yet in possession of data which may confirm this assumption.

In connection with the latter experiments we arrived at the conception of the speech level of control of identification processes. The existence of this level of activity of the visual system once more and from another aspect indicates that the formation of man's perceptual activity is associated with the fact of his mastery of historically formed opera-

tions. in this case. speech operations underlying the system of verbal meanings. Thus the wealth of perceptual possibilities specific of man is contained in the wealth of the experience of man's cognition.

5

Now to sum up.

The aim of our study was to apply to visual perception the approach issuing from the concept of mental processes as a special form of activity representing a derivative and at the same time a condition of activity which practically connects man with the world of objects that surround him.

Since the scientific bases of this general approach lie in a very wide range of psychological facts which cannot. of course. be considered here. we shall limit ourselves to discussing only a few questions specially bearing on the problem of visual perception.

Following the results of our experiments we had to carry on our exposition simultaneously along many lines. Now we shall try to sum up the data we obtained. characterising the function of different links of the visual system.

We shall start with the effector link of the visual system. Some of the functions it performs were omitted by our study, namely, the functions of adaptation (accommodation, convergence) and reflex aiming of the eyes. We shall not dwell on these functions. Special attention is deserved by the functions of the efferent apparatus of the visual system which may. in the broad sense of the word, be termed object functions.

In the first place it is the function of external eye movements consisting in carrying out object-type operations. These operations include. for example. those described in our experiments. namely. measuring the perimeter of a rectangle or counting the hatches drawn on a test object. As was already mentioned. these voluntary. "learned" operations originally form in external manual activity with objects performed under visual control and later are transferred wholly to the visual system and become the "behaviour of the eye". That this function of the external motor apparatus of the visual system does not boil down to a setting-shifting function follows from the mere fact that

operations of this kind are retained with objects whose size does not go beyond the limits of the *fovea centralis*.

We started with a description of the operating-object function because exerting overall perceptive action it comes most clearly to the fore.

An object function in the broad sense of the word is also the function of examination, i.e., the function which ensures orientation in the object. These movements include those connected with initial orientation in the field and the movements which serve to isolate, unite and analyse the elements of objects. The movements performing this function are characterised by the fact that they are subject to the particular strategy which is commensurate with the sensory possibilities of the visual system. Sometimes this "strategy" is determined by the problem with which the subject is faced and the logic of the object, but sometimes is imposed from without, for example, by direct instruction.

The characteristic feature of the movements connected with this function, unlike the type of movements described above, is that they do not realise the total composition of the operations required by the corresponding perceptual problem, but only prepare and serve their execution which is effected by internal processes. That is why further characterisation of the functions of the effector link of the visual system necessarily shifts the analysis on to this new plane, the plane of considering the system's internal processes proper. Since these internal processes do not have their direct and adequate external motor expression we can judge about them most probably by the data of an analysis of the functions not of the motor, but of the sensory link of the system.

As we have seen, the sensory link of the system also performs a number of functions, in the first place the function of afferentation of the motor processes which we have named extrasystemic, i.e., which do not participate in the work of the visual system itself. Such are, for example, the hand movements with the tumbler in response to the appearance of a light signal in the field of vision, the movements forestalling the identification of the signal. In this case the signal plays the role of a trigger stimulus, but it cannot be said that this stimulus is *perceived* by the subject beforehand, if we mean the concept of "perception"

in its concrete psychological sense. In this function the retina is rather an organ of reception than an organ of perception. But this function of the retina also serves the activity of the visual system itself, its apparatus which effect the muscular (accommodation, convergence and retinal tuning of the eye which remained outside our study) and its reflex setting movements. This function apparently presupposes a multichannel retinal inlet and, correspondingly, a possibility of simultaneous reception of stimuli and at the same time a "zonal" structure characteristic of the retina, expressed in a diminution in its sensitivity and refractive power in the direction from the foveal part to the periphery. Thus this simplest function is based on a projection, "screen" effect, *but this effect does not create a perceptual image of the object and is incapable of passing into it.*

Another function of the specific sensory link of the visual system, which is quite clearly observed in experiments, is the function of receiving pre-information. This is also an afferentation function, but, unlike the former, it yields not a tuning or set for the object, but an *orientation* in the object necessary to carry out particular perceptual operations. Owing to this function the eye "does not lose itself" in the complex object and is able to follow the object, break up its elements—"work" with some and digress from others; it also underlies the original visual hypotheses verified in the process of subsequent work of the visual system. This function also presupposes the existence of a screen retinal effect, but, according to experimental data, this effect is sharply limited in volume ("pre-information fields") and under natural conditions of perception extends only to the zone closest to the fixed element of the object. It goes without saying that this effect also fails to be directly transformed into a perceptual image, which is a product of the activity of the visual system as a whole, and only controls it.

Lastly, the specific sensory link of the visual system performs a perceptual function proper. Above we called it an "information" function, implying by it that it supplies the preliminarily isolated informative elements of which the visual picture of the object, i.e., the central perceptual image free of noises, is created. Unlike the retinal projection effect which performs the function of

afferentation of the processes in the visual system, this image is a *product* of its activity. That is why it is free from distortions of the projection retinal effect, conditioned by the structure of the retina itself, and from the unavoidable internal noises which arise in the peripheral apparatus of the visual system.

Thus the activity of the visual system consists not in transmission of the retinal screen effect to the centre, but in that, on the basis of this effect, it builds a central image commensurate with the objects projected on the retina.

Thus, we have arrived at somewhat paradoxical conclusions.

One of them concerns the "screen effect". It consists in the fact that the retinal screen effect is removed by the work of the visual system which creates the perceptual image proper, i.e., also a "screen" effect, but a central, internal one.

The other conclusion bears on understanding the term "visual inlet". We are in the habit of associating the word inlet with the concept of some admitting space characterised by maximum values expressing the quantity and quality (parameters) of the signals which it is able to admit. In this case it is held that its role is passive, that it does not take part in the subsequent processes of treatment of the information. It is a different matter with the visual inlet which, as we have seen, is active; this means that it is not merely an inlet, but a special "working inlet".

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DEVELOPMENT OF PERCEPTUAL ACTIVITY AND FORMATION OF A SENSORY IMAGE IN THE CHILD

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Guided by I. M. Sechenov and I. P. Pavlov's physiologic theory of orienting reflexes Soviet psychologists—A. N. Leontyev (1959), B. G. Ananyev (1960), L. M. Wekker (1959), P. Y. Galperin (1965), A. V. Zaporozhets (1941, 1960), V. P. Zinchenko (1962), B. F. Lomov (1959) and others—have shown in their investigations that a process of perception is a peculiar actions aimed at examining an object, creating its model, forming its perceptual image.

An important part in such perceptual actions, at least at early genetic stages, is played by their effector, motor components in the form of, for example, movements of the hand palpating the object or of the eye tracking the contour of the perceived object. The function of this type of orienting-exploratory movements is to examine the object, to "form a likeness" (A. N. Leontyev), to model its properties.

Modern experimental data attest that the motor components of perceptual activity play an important role not only in tactile and visual, but also in auditory processes (B. M. Teplov, 1947; A. N. Leontyev, 1959; and others), in the sphere of kinaesthetic perception (A. V. Zaporozhets, 1960; Y. Z. Neverovich, 1963, and others), etc.

As is well known, children are born with a number of unconditioned orienting-set reflexes consisting in movements of the receptor apparatus in the direction of a new stimulus, its fixation, following its shifting, etc.

But such unconditioned reactions constitute only the basis for the formation of perceptual activity which goes through a long course of development all through childhood and is influenced by the conditions of life and training.

A number of studies conducted by us and our associates at the Institute of Psychology and the Institute of Preschool Education of the Academy of Pedagogical Sciences, and at the Department of Psychology of Moscow State University were devoted to the development of perceptual activity in the tactile process in children (T. O. Ginevskaya, A. G. Ruzskaya et al.), visual perception of objects (Z. M. Boguslavskaya, L. A. Venger, A. G. Ruzskaya et al.), pitch discrimination (T. V. Yendovitskaya, T. A. Repina, T. K. Mikhina et al.).

We shall now dwell in greater detail on the results of a study conducted by one of us (V. P. Zinchenko, 1962) in the development of perceptual activity in children in the process of visual perception of forms of objects. This study has revealed certain common characteristics of the ontogenesis of human perception.

Despite the fact that this process had been rather thoroughly studied before, only its productive aspect had been subjected to precise measurement, the characteristics of the processes of examining or identifying forms, particularly the peculiarities of the motor components participating in these processes, dropping out of the investigators' field of vision. We, on the contrary, concentrated our attention mainly on the behaviour of the eye in the process of visual perception of objects.

To record the eye movements, a PSK-24 wide-film camera for scientific films was used. The filming rate was 12 sequences per second. The position of the eye in a sequence-by-sequence analysis was determined by the centre of the pupil. In the calculation of the number of movements and fixations a 1-2° shift of the eye was considered a movement (for a detailed description of the method see V. P. Zinchenko, 1956). Asymmetrical figures were used as test material. The figures measured 30 × 40 cm. In the centre of the screen on which the figures were demonstrated there was an opening containing the objective of the camera.

Twenty-four preschool children of four age groups (3, 4, 5 and 6 years old) took part in the experiments. The children were given the following tasks (during the performance they were filmed): 1) examination of a figure (20 seconds); 2) watching a pointer moving along the contours of a figure (slow circumscription of the figure—15-16 seconds and fast circumscription—5-6 seconds); 3) repre-

sentation of a figure (not more than 20 seconds). These three tasks were given to a group of 12 children—3 children from each age group.

The second group also consisting of 12 children was given 2 tasks: 1) recognition of figures after preliminary acquaintance with them (time for recognition—not more than 15 seconds); during the preliminary acquaintance the eye movements of the children of this group were not recorded; 2) examination of topical pictures (time for examination—40 seconds).

Before the beginning of the experiments all the children were accustomed to the noise made by the camera and the atmosphere in which the experiments were conducted. In the experiments of becoming acquainted with objects and in those of recognising figures the subjects were asked carefully to examine (or recognise) figures on the screen in order that they may later find them among other figures. The successful acquaintance with the demonstrated figures and the success in picking them out of other material were studied by us without filming the eye movements.

We shall now describe the characteristics of perceptive actions of children of different ages.

In 3-year-old children examining a test object the eyes move inside the figure (Fig. 1). The children's attention is attracted by the objective of the motion-picture camera. A single eye movement along the axial line of the figure is observed. The number of movements made in a rather long period of time is very small (24 movements) compared with those made by children of other ages (Table 1). There are no movements along the contours of the figure at all. The periods of fixations are much longer time than in older children. This method of becoming acquainted with an object is productive of poor results when attempts to pick out the figures from among other figures are subsequently made. In these experiments, as in those which were not filmed, half the answers were wrong, the children confusing very different figures.

Three-year-old children do not quite understand the task of acquainting themselves with an object or perform this task by inadequate methods. They cannot as yet pick out in the object the features which may help them to recognise it in the control experiment. The sensory content

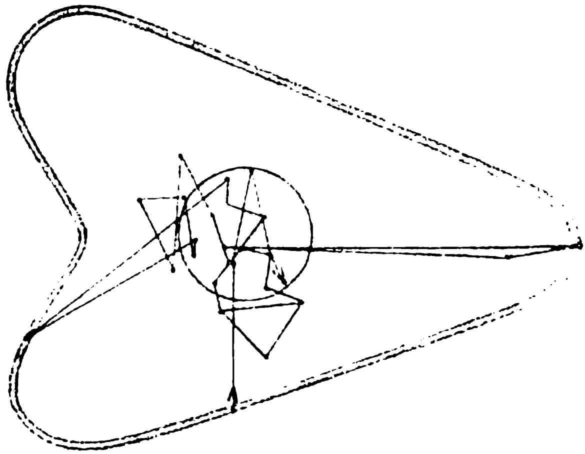

Fig. 1. Trajectory of the eye movements of a 3-year-old child examining a figure (20 seconds)

on which the children of this age orient themselves is not quite clear. It may be assumed that it is the size and area of the figure, but not its form. But even with these characteristics their acquaintance is very cursory and imperfect. In 3-year-old children perceptual activity with regard to the given sensory content is apparently only just beginning to form.

In 4-year-old children acquainting themselves with an object the eyes also move mainly inside the figure. Judging by the trajectory of the eye movements it may be very definitely said that these children orient themselves on the size and area of the figure. Quite many wide, sweeping movements by which they seem to measure the figure are observed. At the same time there are groups of fixations closely located to each other and pertaining to the most typical characteristics of the figure. Hardly any movements along the contours of the figure are observed also in children of this age. As in the younger children quite a number of fixations falls on the objective of the camera. The number of movements made by 4-year-old children in 20 seconds is twice that made by the younger subjects, and their fixations are, consequently, of shorter average dura-

tion. This method of acquaintance is productive of better results in picking out figures in control experiments.

The characteristics of the eye movements of *5-year-old children* closely resemble those of the 4-year-old children. The only essential difference is that 5-year-old children quite thoroughly examine one, most characteristic part of the figure's contour. They perform as many eye movements as the 4-year-old children. They make hardly any mistakes in picking out figures in the control experiments. However, a considerable part of the figure remains unexamined as in the case of the younger children. As in the experiments with 3-year-old children we cannot say that 5-year-old children have already picked out such aspects in the object which enabled them to accomplish their task by an adequate method. In addition to orientation on the essential characteristics of the object they largely orient themselves on secondary characteristics (eye movements along the central part of the figure).

Only in *6-year-old children* did we discover fully-formed methods of perceptual activity. Fig. 2 shows that their eyes move almost entirely along the contours of the figure.

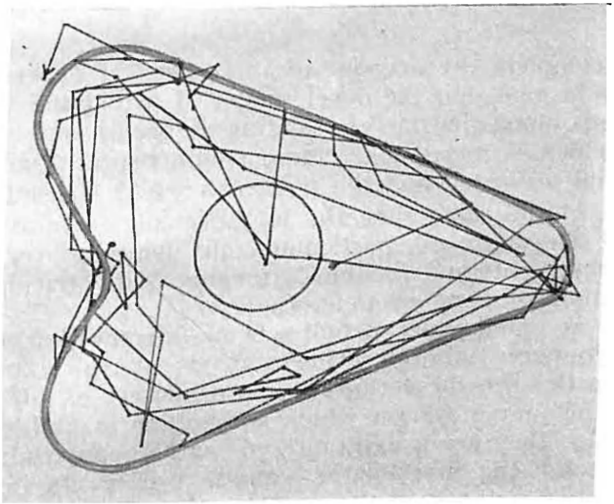

Fig. 2. Trajectory of the eye movements of a 6-year-old child examining a figure (20 seconds)

This means that the children of this age have already determined the most informative characteristics of the object that have to be examined. At the same time the plate also shows movements along the "field" of the figure, but these movements are much fewer and apparently perform the useful function of estimating, measuring the area. These children are observed to make many more movements than the younger children and, consequently, their fixations are still shorter (Table 1).

Table 1

Number of Eye Movements per Second during Perceptual and Identifying Activity

Age of subjects	Number of eye movements	
	during perception	during recognition
3 years	1.2	3.5
4 „	2.4	3.1
5 „	2.3	3.3
6 „	4	2.7

To complete the account of this series of experiments, it may be said that the development of perceptual activity proceeds along the line of isolating a specific sensory content which is increasingly more commensurate with the material presented and the task with which the subject is faced. At the same time the methods of examining the object are improved, particularly the temporal regime of eye movements and fixations changing quite sharply upon transition from one age to another.

The accepted experimental scheme is somewhat alien to the younger children. However, we have consciously chosen this scheme because it has a number of advantages over the play situation which is familiar to children and in which they are usually offered familiar material. In the latter case the investigator cannot isolate the stage of perceptual activity in the making, the stage of search of the sensory content which is specific of the object, and deals essentially with such activity in which the percep-

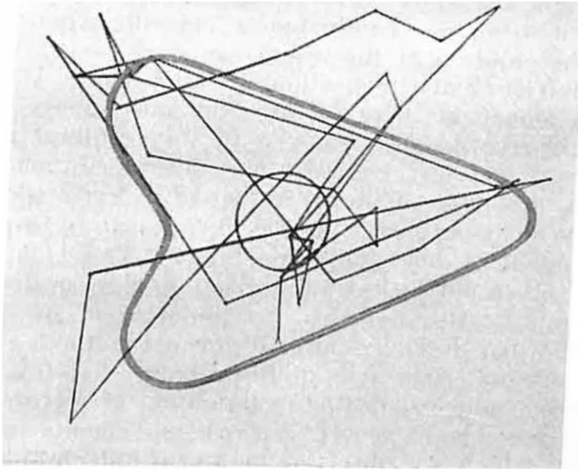

Fig. 3. Trajectory of the eye movements of a 3-year-old child recognising a figure (9 seconds)

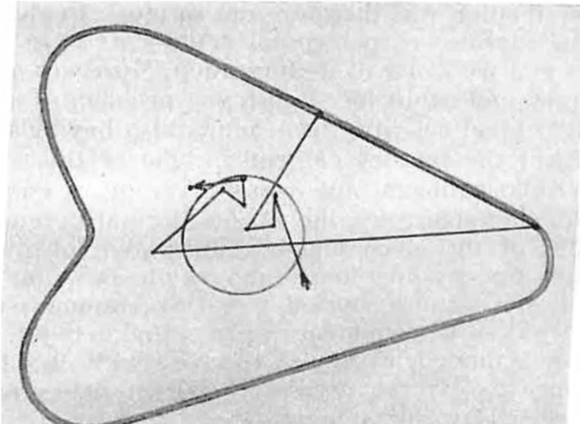

Fig. 4. Trajectory of the eye movements of a 6-year-old child recognising a figure (4 seconds)

tual components proper are mixed with recognition components, the age differences being much less evident.

In conclusion we conducted a control experiment in which the children of the tested age were shown pictures of familiar content (illustrations to fairy-tales). While the children looked at these pictures the movements of their eyes were recorded. An analysis of the resultant material failed to detect any essential age differences among the children. A sample of the trajectory of a 3-year-old child's eye movements is shown in Fig. 5. Analogous trajectories are observed in older children (Fig. 6). These data attest that a perceptual task—familiarisation with more or less known material—may also be undertaken by younger children when they have already formed methods of examining such materials. It is quite probable that (in the case of younger subjects) during examination of pictures it will also be possible to record the eye movements analogous to those which we observed in 3-year-old children when they looked at figures. It is as yet difficult to say at what age this may be discovered, at 2 or 1 $^1/_2$ years.

From the aforesaid it is clear that the level of development of perceptual activity is not an absolute characteristic of age. It must always be correlated with the material presented as the object of this activity. The object of our investigation was therefore not so much to elucidate the age peculiarities of perceptual activity as to establish its genesis and the order of its formation. Moreover, adults, too, are now and again faced with the problem of formation of perceptual activity, these adults also having to find in the object the sensory content specific of the solution of a particular problem and to isolate from an enormous number of characteristics the most informative and adequate aims of the given activity. Formation of the skill of reading topographic maps and of deciphering aerial photographs is quite a vivid, but not exceptional example of such a way of development of perceptual activity. Adults learning deciphering, as is also the case with children, do not at once isolate the necessary characteristics or form the correct strategy of examination.

The problem of formation of perceptual activity is not confined to preschool age. This problem arises each time a subject encounters new reality, whether a geometric form, a picture, a geographic map or an aerial photograph.

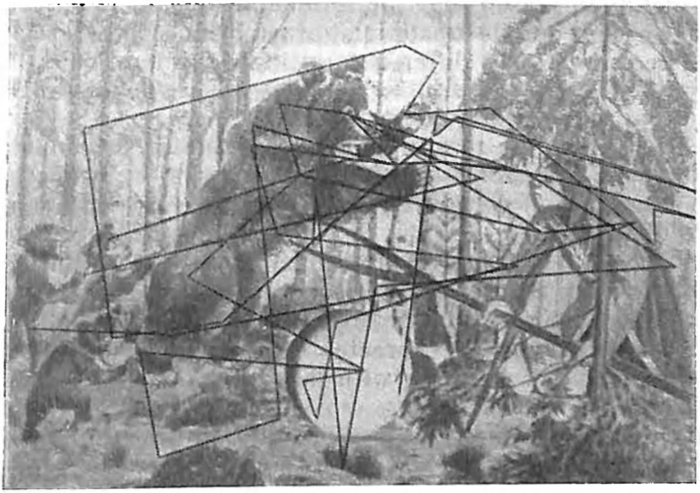

Fig. 5. Trajectory of the eye movements of a 3-year-old child examining a picture (20 seconds)

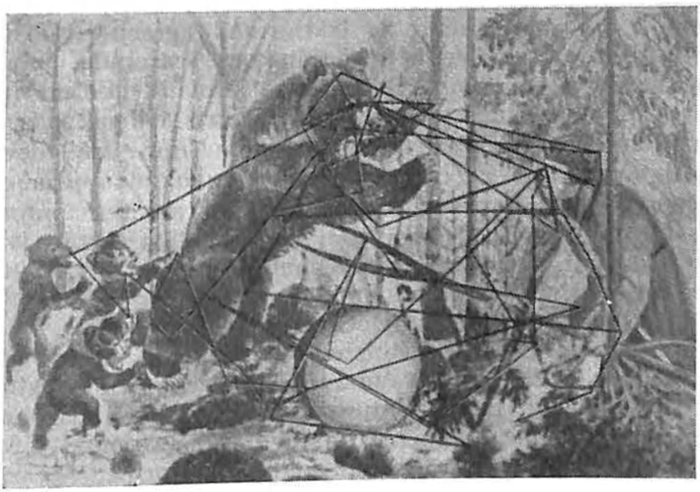

Fig. 6. Trajectory of the eye movements of a 6-year-old child examining a picture (20 seconds)

It stands to reason that the formation of perceptual activity depends on the material toward which it is directed. There may also be differences in its formation determined by the degree of arbitrariness, etc. The details of this process are subject to further investigation.

Such are some results of the study of the development of visual perceptual activity. Similar data were received in the study of the development of the sense of touch in children.

In T. O. Ginevskaya's experiments (1948) blindfolded children of preschool age were asked to acquaint themselves by means of touch with objects placed on the table. It turned out that the character of the movements of the palpating hand changed with age. In younger preschool children (3-4.5 years) these movements are still of a primitive character and are insufficiently differentiated from working, executive movements. Upon the very first contact with objects the children try in some way or other to manipulate them (roll, pull, strike) and in the process of this sort of practical or play activity acquaint themselves with the displayed things. Later (4-5 years of age) the palpating actions of the hand are separated from its practical, executive actions. However, they are still mainly not of an exploratory, but of a setting, fixing character. Trying to find out what the thing is the child grasps it firmly with his fixed hand without making any searching, palpating movements. Lastly, in older preschool children (6-7 years old), in addition to the afore-described methods of palpation, more perfect methods become quite well developed. Fine palpating movements of the hand appear; by means of these movements the children trace the contours of the object, test its resiliency, examine its texture, etc. As the result of this the tactile images forming in the child become richer in content and more precisely correspond to the characteristics of objects perceived.

Subsequently V. P. Zinchenko in association with A. G. Ruzskaya and others undertook a more detailed study of this process, using film recording of the movements. At the same time Zinchenko discovered a profound difference between the perceptive actions performed by the child in identifying more or less familiar objects and in acquainting himself with entirely new, unknown objects. Thus it is necessary to distinguish two different types of

perceptual activity—identifying activity and activity of familiarisation. The identifying activity of 3- and 6-year-old children is illustrated in Figs. 3 and 4. In this case we shall discuss the genesis of children's familiarisation activity.

The experimental study of touch was conducted as follows. The child was placed behind a screen in front of which, on a tripod there was a large plane asymmetrical figure. The child was asked to acquaint himself with the figure by palpating it in order that he may later find it with his eyes among other figures. The experiments were recorded on a film. The palpation of each figure was filmed for 60 seconds.

A comparison of the data obtained in children of different ages makes it possible to characterise the stages of development of the hand movements performed by the child as he palpates the object. Thus the hand movements of 3-year-old children are rather grasping than palpating. Often, instead of examining the figure, small children play with it. For example, placing the palms of his hands on the edge of the figure the child taps it with his fingers, the palms remaining still all through the exposition of the object.

The hand movements of 4-5-year-old children largely resemble those of 3-year-olds, but contain some new elements. The same grasping of the object with the phalanges of four fingers and the palm lying on the edge of the figure are observed. But the hands of 4-year-olds do not long remain still, and the children quite soon begin to acquaint themselves with the object more actively, doing it with the palm and the anterior surface of the phalanges of the fingers. The tips of the fingers hardly participate in the process of palpation. The children usually palpate the object with but one hand.

Children 5-6 years old begin to palpate the figure simultaneously with both hands which either move towards or away from each other. However, the entire contour of the object is not systematically tracked as yet. The children usually confine themselves to a thorough examination of some characteristics of the figure, for example, some hollow or projection, without correlating them with each other or elucidating their location on the figure as a whole. Only in 6-year-olds is it possible to observe a successive

tracking of the entire contour of the figure with the tips of the fingers, the children seeming to reproduce, model its form with their palpating movements. The transition to these new and more perfect methods of becoming acquainted with the object lead to much more effective perception, which was detected in the control experiments with visual recognition of the figures formerly presented for haptic acquaintance. Whereas children under 5 years of age made many mistakes in recognising objects, 6-year-olds, who carefully tracked the contours of figures with the palpating hand, later unmistakably recognised these figures.

The foregoing data attest that perceptual activity is not given to the child in an inborn, ready-made form, but that it forms and develops in the course of childhood.

The question as to the moving causes of this development arises. The works of A. N. Leontyev, B. G. Ananyev, B. M. Teplov and others warrant the conclusion that the processes of sensation and perception, like the other mental processes, do not develop isolatedly, but in the context of the different forms of the subject's activity, practical activity in the first place.

The studies we have carried out together with our associates warrant the following characterisation of the role of practical activity in the development of perception in the child.

At the early stages of development a more or less correct reflection of reality may arise only as the result of practical activity with objects, the sensory processes proper playing a dependent, subordinate role. Only in the process of this activity as a whole, including both its sensory and motor components, may an adequate model of the object be created; repeatedly compared with the original and made more precise in accordance with its characteristics the model in the end leads to emergence of an adequate perceptual image in the child. For example, an infant who is learning to grasp things with due regard for their position, size and shape models these spatial properties with his hands in the same way as later, having learned to walk in conformity with the relief of the terrain, avoiding obstacles and following a certain direction, he models in his locomotor movements the situation in which his activity is carried out. Such modelling of the

surroundings in the process of practical activity, which contains both motor and sensory components (G. Piaget, 1948, examining such cases speaks of formation of "sensorimotor" schemes in the child), apparently plays a decisive role in the early ontogenesis of sensory processes which, participating in this modelling, begin to reorganise themselves and, in addition to the signal, trigger functions that had arisen earlier, also begin to perform functions of reproducing, representing reality.

The further development of the child's perception is connected, according to L. A. Venger (1965), with subsequent complications of the child's activity, with transition from the simplest forms of direct activity with objects to activity with tools and from this to productive activity which requires not only consideration of the existing situation, but also creation of new objects in accordance with a well-known model.

The experiments conducted in our laboratory show that at early stages of development, when it is impossible to create an adequate perceptual image in small children only by visual or tactile acquaintance with an object, such an object may be formed in the process of practical manipulations with this object. Thus in Zinchenko and Ruzskaya's (1960) experiments children of different preschool ages were asked to acquaint themselves with wooden asymmetric plane figures by various methods: a) only by viewing them, b) only by palpating them, c) by viewing and palpating them, and d) by practical activity—fitting the figures into corresponding holes in a board.

The sensory effect of all these different methods of acquaintance with the material was checked in control experiments in which the children had to recognise (visually) the formerly perceived figure among unfamiliar figures. The resultant data (Table 2) attest that in the case of younger children (3- and 4-year-olds) a purely sensory, "theoretical" acquaintance with a new complex object produces poorer results than practical manipulation. And only later, towards 5 years of age, the formation of perceptual activity (in the given case visual perception) reaches the level when they begin to catch up in their cognitive effectiveness with the processes of practical manipulations with objects.

In the process of practical activity children not only isolate the different qualities of various objects, but also elucidate some of their interrelations.

In Venger's experiments 2-3-year-old children were given the task of drawing a solid geometrical figure, facing them with its square, rectangular or triangular plane, through one of the holes in an experimental grill, for which it was necessary to choose a hole corresponding to the form and shape of the figure (see Fig. 7).

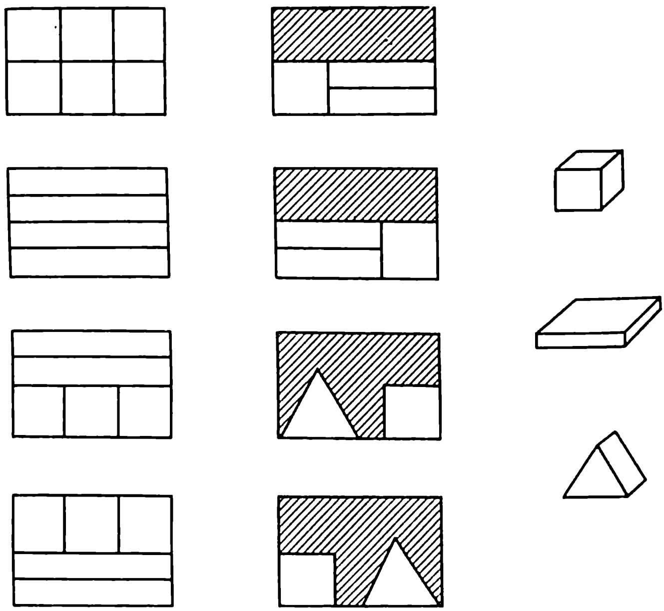

Fig. 7. Illustration for L. A. Venger's experiments

At the outset this task was accomplished by all the children only by practical manipulation, by the trial-and-error method. Two-year-olds did not rise above this level even after repeated attempts. As to 3-year-olds, these children gradually learned to compare the figure and hole visually on the basis of their practical correlation. In this case visual perceptual activity "borrows", so to speak, the method of accomplishing the task from the practical activity. The child shifts his gaze several times from the figure

Table 2

Mistakes of recognition (in %%) after using different methods of examining objects by preschool children

(Experiments of V. P. Zinchenko and A. G. Ruzskaya)

Methods of examining	Age of children			
	3-4	4-5	5-6	6-7
Looking only	50	28.5	0	2.5
Touching only	47.7	42.3	25	23.1
Looking and touching . . .	30.8	21	11.5	1.9
Practically operating . . .	15.4	10.5	0	0

to the hole, as though visually fitting them to each other, and then unerringly accomplishes the task even under entirely new and unfamiliar conditions.

Similar results were obtained in our laboratory by A. Kasyanova who studied perception and transposition of the relations of the values of the perceived objects. The age of the children participating in the experiments ranged from 1 1/2 to 7 years. Each subject had two boxes before him; boards with holes of different forms and sizes could be fitted into these boxes. The holes were covered with frosted glass under which there was a bulb lighted by means of a switch fastened on the outside of the box. Switching created a situation in which the appropriate bulb could be lighted only by pushing the button near the large figure; the latter served as reinforcement of the performed action.

Despite the assertions of the Gestalt psychologists, the elaboration and transposition of the reactions to the aforesaid relations turned out to be much less effective in younger children than in older ones. An attempt to organise a repeated shift of the gaze from one figure to another (which produces considerable changes in perception of relations in 5-7-year-old children) with the aid of the experimenter's instructions did not noticeably affect the youngsters. Then the children were taught to compare the objects practically, according to size, by fitting into each other cups, cardboard cubes and other things of different sizes. When the main series of experiments were

resumed after these training experiments, the children produced higher results in perceiving and transposing relations than they had before comparing them practically, according to size (Table 3).

In finishing the review of the data on the role of practical activity in perception of objects at different stages of the child's development we shall dwell on the experiments conducted by V. P. Sokhina who studied the influence of construction on the development of visual analysis of complex forms in children of preschool age. Continuing the well-known studies of A. R. Luriya, Sokhina showed that without appropriate training 3-4-year-old children cannot isolate elements of complex form, cannot, for example, point out of what parts the given figure consists. However, after a series of practical exercises in construction, by creating real structures from elements of different forms and sizes, the children began to analyse figures purely visually thereby also anticipating the results of their practical activity. The effect of such training is extensively transferred to new conditions and is revealed, for example, in finding the prescribed element included in a complex whole (as is the case in Gottshaldt figures, etc.).

The foregoing data furnished by our studies of the visual and tactile perceptual activity of children characterise the development of perception taking place, so to speak, spontaneously, without specially organised sensory training. Under such conditions, as in any uncontrolled, spontaneously operating process, perceptual activity forms quite slowly and only towards the end of preschool age, and not in all cases at that, do more perfect methods of

Table 3

Threshold of pitch discrimination in preschool children (Difference in tone)

Experimental situation	Age of children			
	3-4	4-5	5-6	6-7
Before training	4.8	3.4	2.4	1.7
After training with "concrete modelling"	2	1	0.85	0.60

examining the perceived objects and of modelling their characteristic properties begin to form.

It may be supposed that with specially organised training the rates of development of children's perception may be considerably quickened and more perfect methods of perceptual activity will form sooner than under usual conditions.

When organising sensory training and attempting to make the process of developing perception controllable it is necessary to consider certain general peculiarities and regularities of this process, which in some way or other also manifest themselves if the process operates spontaneously.

An analysis of the foregoing experimental data and certain general theoretical considerations impel us, upon examination of the problem of sensory learning, to devote special attention to the following peculiarities of perceptual activity and the process of its formation in the human ontogenesis:

1) As the studies of P. Y. Galperin (1959), A. V. Zaporozhets (1960) and others show, the success of forming any practical or mental action decisively depends on how its orienting part, its orienting basis has formed. In this respect perceptual activity is no exception. Although on the whole, in its function, it is orienting, it contains both executive and orienting components, the latter playing the leading role in the structure of such activity.

For a rational organisation of sensory education it is necessary to devote special attention to the formation of the orienting basis of perceptual activity, the elaboration of a certain preliminary idea of the distinctive peculiarities of the perceived objects, which will determine the method and general strategy of examining these objects.

2) As the studies conducted by A. N. Leontyev (1959), A. V. Zaporozhets (1963) and others have shown, the ontogenesis of human perception is characterised by the fact that the orienting basis of perceptual activity forms in the child not only as the result of individual experience, but also through mastery of the social sensory experience, through acquisition of the sensory culture created by man.

As the result of many years of experience in production, science and arts mankind isolates from the multiformity of the peculiarities of the surroundings only some, in a

definite manner quantable properties, as the most important, essential and necessary in man's social practice. Such socially-formed systems of perceived characteristics include the generally-accepted scale of musical sounds, grids of phonemes of different languages, system of geometrical forms, etc.

In the course of childhood an individual masters such systems of "sensory properties" of things isolated by mankind and learns to use them as measures or standards in examining the objects he perceives and in determining their characteristics.

A rational organisation of sensory education necessarily presupposes not only simple "training" of the sense organs, as it was envisaged by Montessori, but also a systematic mastery by children of the socially elaborated sensory standards (the psychological and pedagogical aspects of the given problem are elucidated in the book *Sensory Education of Preschool Children* edited by A. P. Usova and A. V. Zaporozhets, Moscow, 1963, Russ. ed.).

3) The formation of the orienting basis of perceptual activity in the course of mastering the social sensory experience essentially differs from the spontaneously operating process of its formation. However, both cases involve a transition from external material activity with objects to ideal activity, to activity performed in the field of perception. The general regularity of transition "from without to within" is observed in both cases. The only difference is that with a special organisation of sensory training the spontaneous activity aimed at achieving practical ends and producting a cognitive effect only as a side product, is replaced by a specially organised material activity which is from the very outset subordinated to cognitive tasks and is aimed at modelling the characteristics of perceived object.

Such concrete objective modelling, as the studies of our laboratory show, plays a very important role in the development of the child's cognitive processes in general and the development of his perceptual processes in particular. The following are some examples. Z. M. Boguslavskaya studied the development, at preschool age, of visual perception of concrete objects (spade, cup, apple, etc.) and of abstract geometrical figures. It turned out that not only all the younger children (3-5 years old), but also a large

number of the older ones (5-7 years old) limit themselves under these conditions to a very cursory examination of the object on display so that the image they form is very incomplete and fragmentary. By this method of familiarisation children quite successfully recognise the object by one or two typical characteristics, but cannot reproduce it in a drawing or appliqué because representation requires a higher level of organisation of the perceptual processes, a more complete and detailed sensory image. In subsequent experiments the children were taught to model the form of perceived objects, making them up from matches, strips of paper, etc. The activity of the children was organised in a definite manner and the children were especially explained that this activity would help them better to acquaint themselves with the object and then more correctly to draw it. Under these conditons the models made by the children were not an end in themselves, were not the end product of their activity (as is usually the case in drawing lessons), but proved to be a means of solving certain cognitive and then practical problems. After such exercises the effectiveness of the perceptual processes of all children sharply increased, manifesting itself, for example, in a noticeably more precise graphic representation of the perceived object despite the fact that in the given case the children were not taught to draw at all.

Similar methods of concrete objective modelling were used by G. A. Kislyuk and V. P. Sokhina in teaching children visual analysis of a complex form under conditions of construction according to a prescribed model.

As the aforementioned study conducted by A. R. Luriya has shown, preschool children cannot purely visually break up the assigned model into the elements of which it must be constructed. Usually they solve the problem practically, trying various combinations until they achieve the requisite result. In order to transfer the children from this primitive level of solving the problem to a higher level, Sokhina somewhat modified the problem, attaching the main importance not to the practical result, but to the preliminary orientation under the conditions of its achievement. For this purpose the model and the elements (flat, differently-formed figures) were placed under glass (Fig. 8) and the children had to indicate beforehand the figures they needed

to reproduce the assigned model. Then the experimenter took the figures indicated by the subjects from under the glass und the subjects set about solving the problem practically; in the course of the solution of the problem it was ascertained whether or not the preliminary visual analysis of the complex form was correct. After a child discovered, as a result of unsuccessful trials, that the given problem was difficult and that he was making mistakes in choosing the requisite figures he was asked to use the method of objective modelling of the conditions of the problem. At this point the children were given patterns made of plain white paper and precisely corresponding to the model and its elements (these latter are shown in the plate as white figures) and by superposing the copies of the elements on the copy of the model were taught to elucidate the parts from which the figure corresponding to the model may be constructed.

The training in activity with this sort of models proceeded differently in children of different ages. Three-year-olds generally learned the prescribed method of activity with considerable difficulty and the training failed to produce any appreciable results.

Four- and five-year-old children had less difficulty in learning to operate with paper patterns, but this activity and its results were not for them a model for subsequent solution of a constructive problem, but formed an independent practical achievement. First they superposed copies of elements on the paper pattern of the model and then, entirely independently of the solution of the first problem, began to pick out cardboard figures from under the glass in order to construct a new structure. To subordinate the former activity to the latter and to impart a truly modelling character to it,

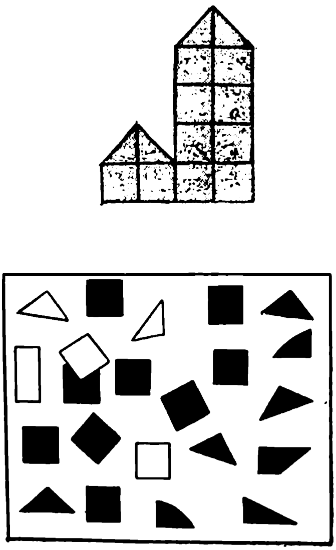

Fig. 8. Illustration for V. P. Sokhina's experiments

it was necessary to exert additional influences aimed, in part, at enhancing the value of the main constructive problem (superposing a beautiful structure by means of figures cut out of glossy coloured cardboard) and somewhat to diminish the attraction of modelling (operating with patterns of plain soft white paper) which was supposed to become for the children but a means of solving the main problem.

As to the older children (5-7-year-olds), they mastered the suggested method of object modelling without any additional exercises and made adequate use of it in achieving the required practical results.

As a result of such training all 4-7-year-old children considerably improved their visual analysis of complex forms and in most cases could correctly point out the geometrical elements of which the given model may be made up and approximately how these elements must be arranged.

In the afore-described cases the object perceived by the child and the model of this object he creates lie, as it were, in one plane and belong to one sensory modality. However, as the studies conducted in our laboratory show, children relatively early become capable of modelling the qualities of one modality in the properties and relations of another. Such heterogeneous models assume special importance for the formation in children of adequate methods of analysing musical and speech sounds since the acoustic element is extraordinarily mobile and barely perceptible to the child until it is possible to model or, as P. Y. Galperin puts it, to "materialise" it in certain spatial properties and relations of things.

The studies of T. V. Yendovitskaya and T. A. Repina conducted in our laboratory have shown that it is very difficult for preschool children to discriminate between the pitch of pure sounds (produced by a sound generator) and that the differential thresholds established in such experiments are very high.

The forming experiments used objects in whose spatial qualities the relations of sounds were modelled according to pitch. Thus T. A. Repina dramatised before the children scenes with the participation of big daddy-bear who uttered low sounds, somewhat smaller mummy-bear uttering higher sounds, and very small sonny-bear who uttered still

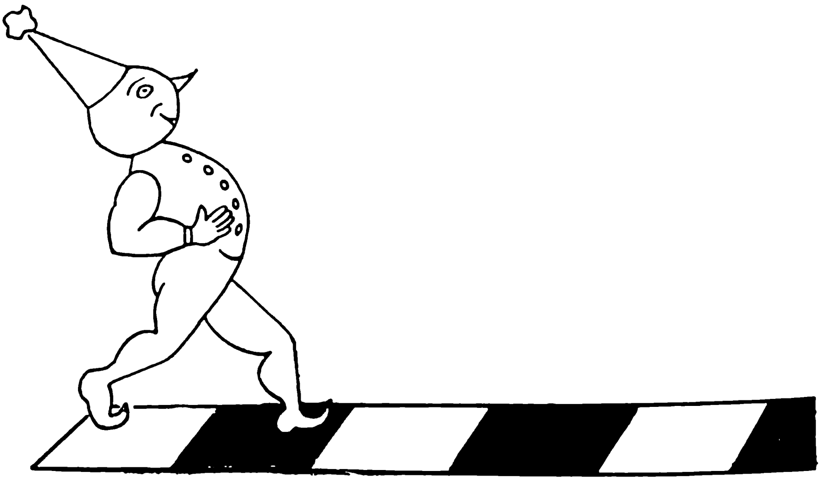

Fig. 9. Illustration for T. V. Yendovitskaya's experiments

higher sounds. After various scenes from the life of all these characters had been enacted by the experimenter together with the children the bears hid in different places and the children had to find them by their voices. It turned out that after such training even the younger children (2-4-year-olds) not only easily distinguished by the pitch the voices of toy animals, but also began more successfully to differentiate any sounds they heard for the first time, sounds which were not connected with any objects they knew (Table 3).

T. V. Yendovitskaya made use of a more complex and at the same time more universal model of sound-pitch relations. She gave the child a rectangular ruler, divided into equal squares, and a doll which had to jump from one square to another in accordance with the sounds which the child heard (Fig. 9).

If the difference was small, the doll had to jump from the first square into the second, if it was somewhat bigger—from the first into the third, etc. In the beginning the child performed these exercises together with the experimenter and then did them himself (unaided).

As Table 3 shows, the training of children in such a method of modelling sound-pitch relations leads to considerably more effective discrimination of sound by pitch.

In coming back to the question of the influence of concrete objective models on the development of perception in children it should be emphasised that as peculiar analogues of sensory images they are not such images just the same, and it is still to be elucidated how external modelling is, so to speak, "internalised", transformed from external to internal.

As we have already pointed out, new methods of becoming acquainted with reality are born of practical activity, in connection with new practical problems the child has to solve. In the beginning they serve to carry out executive activity directly aimed at achieving a certain practical result, and only later, under definite conditions, are transformed into methods of orienting-exploratory, modelling activity.

N. N. Poddyakov (1960) studied the process of formation of skills of controlling relatively complex mechanisms. The child sat at a control panel and by pushing one (or two) of 4 buttons could make a doll move in different directions. The subject was given, for example, a problem of leading the doll around obstacles and bringing it closer to a certain point. Although the experimenter demonstrated the work of the mechanism beforehand, the children could not immediately grasp the principle of its operation and, trying to achieve the desirable aim at once, they began pushing the different buttons in a disorderly manner as soon as they started working on the problem. But with this method of work the doll tossed about chaotically and the requisite result was not achieved. The difficulties the child encountered in the practical solution of the problem prompted him to investigate the situation, a characteristic change taking place in his behaviour. The rapid, strong pressure exerted on the buttons changed to slow, cautious, probing efforts accompanied by following the moving doll with the eyes. In other words, before our eyes the executive acts were being transformed into orienting-exploratory activity and an elementary method suitable for examining various systems of push-button control was being born.

Similar changes occurring, however, no longer in the functional, but in the genetic age plane were observed by Y. Z. Neverovich (1963) in her studies of kinaesthetic perceptions. Children were asked actively to reproduce on Zhukovsky's kinemometer the movement which they had

passively performed before with the aid of the experimenter. Correct reproduction was at first reinforced by the experimenter's encouragement or a flashing of a signal light. It turned out that the movements of younger children (3-year-olds) were markedly executive and aimed directly at achieving the desired result. Quickly and without any hesitation they brought the kinemometer pointer to a certain point and on receiving appropriate reinforcement were boisterously happy; in cases of failure they were aggrieved. No preliminary orientation in the conditions of the problem was in this case made. At higher genetic stages, in 4-5-year-old children, in addition to the aforementioned executive movements, there appear slow, probing movements by means of which the internal, proprioceptive picture of the suggested assignment is elucidated and the model of the future motor act is created (Fig. 10).

The foregoing data illustrate the transformation of the direct actions of the hand from executive into orienting, modelling action. However, we also obtain similar data when we deal with mediate actions which lead to creation of new objects and situations.

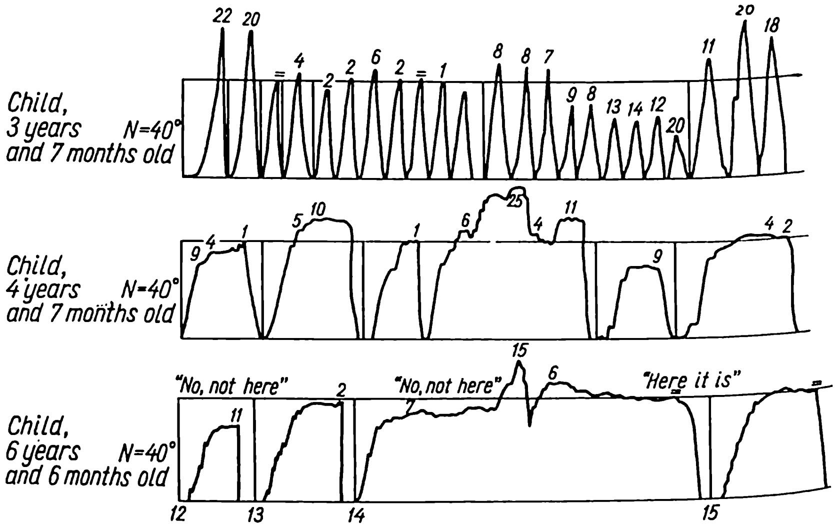

Fig. 10. Reproduction of the prescribed amplitude on a kinemometer by children of different ages

Thus, for example, in the already mentioned studies conducted by Z. M. Boguslavskaya, V. P. Sokhina, and others it was discovered that children first master construction, appliqué or drawing as definite forms of practical activity which lead directly to achieving the results they are interested in. And only after this activity has become sufficiently formed is it possible to communicate a new function to it, the function of examining the situation and of preliminary modelling of the results which must be achieved in the course of subsequent executive activity.

Thus the first and most important stage which characterises the birth of a new perceptual act is transformation of an executive action into an orienting and modelling action.

That is precisely why at the outset the new method of becoming acquainted with an object usually involves the organs capable of performing both practical and gnostic functions as, for example, the hand palpating and manipulating objects or the muscular apparatus of the larynx which, playing a necessary role in social intercourse, at the same time serves as an important agent of analysing musical and speech sounds.

Severed from practical activity and acquiring new, orienting functions the child's actions subsequently undergo essential changes. Thus, for example, any grasping and manipulation of an object give the child certain information about it. That is why at first, as we already mentioned it, children try to utilise the practical acts they have mastered, not only for practical, but also for cognitive purposes. However, the cognitive effect of such acts is insignificant and they must be modified and reorganised in order that they may effectively perform their new cognitive functions. This process of differentiation and specialisation of perceptual activity, as well as its subsequent interiorisation, was investigated in a number of studies conducted in our laboratory.

Thus A. G. Ruzskaya (1958) studied the formation of perceptual activity in the process of discriminating geometrical figures by children of different preschool ages. There were two reaction keys on the table before the child. Somewhat farther there was a toy garage with an automobile. A small screen was suspended above the garage. Geometrical figures were demonstrated on this screen by means of a special device. Upon the appearance

of some figures (triangles) the child had to press on the left key, on the appearance of others (rectangles)—on the right key. A correct choice was reinforced by a toy automobile driving out of the garage.

In training experiments children exercised in differentiating the form on one pair of repeatedly appearing figures. When the differentiation was elaborated the control experiments were started. In these experiments the children were shown, on the aforesaid installation, different figures in different positions. All preschool children made many mistakes in choosing the requisite key. The number of such mistakes was particularly large in the case of 3-4-year-olds (Table 4).

This attests that the perceptual images forming under the given conditions of training prove to be insufficiently constant and generalised, owing to which they fail to ensure the child the ability to solve complex sensory problems.

On the basis of the foregoing assumptions concerning the genesis of perceptual activity Ruzskaya tried in subsequent experiments to teach the child methods of becoming acquainted with the perceived objects. The children were given figures cut out of cardboard, which they could palpate and manipulate. Under the given conditions all the younger and some of the older children used very primitive methods of becoming acquainted with figures. They shifted the figures from one hand into another, touched their angles and put them in heaps without thoroughly examining them. In connection with this the children were subsequently given special training in more

Table 4

Differentiation of geometrical figures by preschool children (%% of mistakes)

	3-4 year	4-5 year	5-6 year	6-7 year
Before training	40	32	17	8
After children were taught how to examine the outline of the figure	11	11	11	3

rational methods of becoming acquainted with objects. They were taught successively to move a finger around the contours of figures, accenting the changes in the direction of the movements at the angles and accompanying these movements by a count (one, two, three).

The examination of triangles alternated with examination of rectangles and of the differences in their metric structure and the number of their angles and sides were elucidated. Thus the child mastered an algorithm of exploratory activity which enabled him to identify any variant of a figure (formed by a broken line) in any position. However, during the initial stages of formation the function of examining and modelling could be performed only by the hand palpating the object, while the eye played an auxiliary role of afferenting and following the movements of the hand. Subsequently the eye was able independently to solve such perceptual problems by successively following the contours of the figure as had formerly been done by the feeling hand.

Interesting transitional forms are observed, the child already discriminating between figures visually, but following the movements of the eyes by abortive movements of the hand which models at a distance the form of the visible object thus organising and correcting the processes of visual examination of the object.

Later children turn to a purely visual orientation, at the outset the eye movements being very extensive, gradually following the entire contour of the perceived figure and modelling its characteristics in every detail.

At the final stages of formation of the perceptual process, after the child has, for example, long practised recognising and discriminating between a certain series of figures, the exploratory movements of his eyes begin successively to diminish, concentrating on various, most informative characteristics of the object (Fig. 4). The highest form of internalisation of the perceptual process is achieved at this stage when, on the basis of external models which arose earlier (for example, created by means of hand or eye movements) and were repeatedly compared with the object and corrected in accordance with its characteristics, an internal model—a constant and orthoscopic perceptual image of the perceived object—is finally formed. Now without extensive exploratory reactions, one cursory glance

at an object, distinguishing one of its characteristics. may as a signal actualise in the child the entire internal model and thereby lead to instant discernment of the properties of the perceived object.

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THE PROBLEM OF PERCEPTUAL CONSTANCY IN THE LIGHT OF THE THEORY OF SET

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1

Although the problem of perceptual constancy is the subject of intensive and fairly developed experimental research, resulting in the establishment of a number of regularities of the phenomenon, the interpretation of its psychological "mechanism" is still in the stage of numerous theories, each of them invariably faced with insuperable difficulties of a factual nature. To reveal the basic difficulty with which, in our opinion, all these theories are faced, we shall here try to touch briefly upon the main *trends* under which these theories may be subsumed.

1. First, the theories which may be grouped together as being all intellectualistic in character. Helmholtz's well-known theory (later somewhat modified by Müller) may in this respect be regarded as classic; a direct influence of this theory is clearly manifest in the modern intellectualistic theories of constancy (Brunswik's theory of "objective intentionality", Volkov's theory of "eye judgement", etc.).

The essence of Helmholtz's theory consists in that it treats constancy of perception as a secondary phenomenon—in a certain measure as a result of unconscious conclusions based on individual experience with regard to actual properties of objects. Since Helmholtz had proceeded from the mechanistic, atomistic conception of sensations, which W. Köhler gave the name of "sensation constancy hypothesis", it is this that accounts for the extreme dualism of his perception-sensation dichotomy severed from each other—a dualism which characterises Helmholtz in general

and his treatment of the problem of perceptual constancy in particular. Sensations are quite non-constant, but in perception they are transformed, corrected under the influence of *judgements and conclusions* based on the subject's past experience. But since *no such conclusions in the process of perception are actually observable* Helmholtz assumes "unconscious judgements", constant perception being built, according to him, on non-constant sensations under the influence of such "unconscious judgements". These latter rest on our conceptions of the objective properties of objects developed in the course of our individual experience. A decisive role in the acquisition of this experience is played by unconscious judgements on the basis of which we work out "scales" for appraising the objective properties of objects.

Modern intellectualistic theories of constancy are also faced with an analogous inconsistency. Their general untenability consists primarily in the fact that they are compelled to resort to intrinsically contradictory concepts of unconscious judgements, "eye judgements", unconscious knowledge, "objective intentionality" of the object, etc., and to assume *unconscious* "appraisal" of the situation or "taking its conditions into account".

Moreover, these theories leave open the question of the mechanism by which this unconscious knowledge or judgement affects perception.

Such modern theories as Volkov's "eye judgement" theory (34), Brunswik's phenomenalistic "objective intentionality" theory (3) and partly Thouless's conception (30), which essentially assumes the factor of unconscious knowledge, must in substance, be subsumed under this group of theories.

True, Brunswik sometimes tries to dissociate himself from the intellectualistic interpretation of constancy, but his theory essentially remains intellectualistic since under constant perception the image of an object ensues, according to this theory, from *objective intentionality* this latter resting, as it does, on a knowledge of the true properties of the object (when "intention" is oriented towards sensory impressions perception is non-constant). True, the author also refers to "automatic situation appraisal" ("automatisch in Rechnung gestelt") in perception, but since he does not explain the nature of such taking into

account it is to be supposed that the "mechanism" of this "taking into account", is also reduced to "objective intentionality" which, according to the author, is responsible for constancy of perception, or we must take it that the question of the "mechanism" remains open and the inconsistency with which any intellectualistic theory is faced remains in force, i.e., the "taking into account" occurs outside conscious intellectual processes.

Brunswik's theory remains intellectualistic, for it is "object intention", i.e., an intellectual phenomenon, that he considers to be the correction factor of stimulation, i.e., the primary sensory impression. That author himself emphasises that "objective intentionality" is a specific attribute of cultured man and is alien to "animals and primitives". However, when that author is faced with the fact of absence of a conscious appraisal of a given situation, he speaks of "automatic taking into account" of the situation, but since the content of this concept is not clarified the difficulty with which the intellectualistic theory is faced remains.

All intellectualistic theories are at variance with experimentally established incontestable facts which basically exclude the possibility of reducing perceptual constancy to processes of an intellectual nature; these are primarily facts of constancy of perception at the lower stages of onto- and phylogeny where there can be no question of influence of the intellect on perception: in infants (during the second half of the first year of life [Frank, 6; Piaget, 2; and others]), in chimpanzees (W. Köhler, 14), in hens (W. Köhler, 14; D. Katz and Rewesz, 13), in chicks (Getz), in fish (Burkamp, 4), etc.

2. Some investigators, beginning with Hering (9)* and down to our days, have been trying to disclose the basis of perceptual constancy by bringing to light a number of "peripheral" factors of perception—components of perceptual, physiological receptor processes. Most of these theories have been disproved by facts in the process of further studies of the manifestations of the "factors" involved.

Hering's classical theory (9), Kraus's double vision hypothesis (17), K. Buhler's *Luftlichtshypothese* (5) and

* For a more detailed discussion of the Hering theory and its relation to that of Helmholtz see (20) pp. 39-41.

others have also been disproved by rigorously established facts. This does not, of course, rule out the necessity of a search for new "peripheral" factors, but regrettably the actual study of such factors is conducted in the direction of a search for specific manifestations of reception of various forms of constancy (mainly constancy of colour and size and, less frequently, constancy of form), and this search therefore overlooks the main problem—that of the general basis of perceptual constancy in general.

3. Nor have representatives of Gestalt psychology revealed the psychological "mechanism" of perceptual constancy, even though some of them (D. Katz, 12; A. Gelb, 7) have experimentally established regularities in the constancy of colour perception, which are particularly important for the understanding of this phenomenon.

Most characteristic of the Gestalt psychologists is their recognition of constancy as an immanent property of perception determined by the structure of the field of perception, but the fact must not be overlooked that they somewhat differ with one another as to the nature of perceptual constancy.

The basic proposition for the representatives of this trend is their denial of the dualistic theory of constancy which considers this phenomenon a *secondary*, complex phenomenon of perception in which the immediate data of perception are corrected by the "higher" functions (Helmholtz, Brunswik, and others). The main principle of Gestalt psychology concerning the "primacy" of perception, its immanent structural integrity, also extends to constancy of perception.

For Köhler constant perception does not differ in its psychological nature from any optic illusion conditioned by the integral structure of the perceived visual field, for example, from the Muller-Lyer illusion. Non-constant perception, as well as the overcoming of these optic illusions, is the result of the perception of an object *isolated* from the visual field, from the structure in which it had been perceived constantly or illusorily (15).

True, Köhler himself pointed out, as early as 1930 (15), the importance for perceptual constancy of practical contacts with objects, particularly the ability of artists to perceive both constantly and non-constantly ("in perspective"), but he conceives the influence of the subject's experience

on the constant or non-constant character of perception as "reconstruction" of integral perception.

It is characteristic that in summing up the work of the corresponding section of the congress of psychologists D. Katona, representative of Gestalt psychology, defined the essence of perceptual constancy as constellation, without even raising the question of the basis or mechanism of this constellation (11).

D. Katz, who made an intensive study of colour constancy in the problem of types of descriptive ("phenomenological") manifestation of colour, arrived at the conclusion that the "taking into account" of a given situation, particularly the general "tint" of illuminance, is of decisive importance for constancy (12). He held that the greater or lesser "central modification" of "peripheral excitation" or "physiological colour" depended on the extent of this taking-into-account. But Katz leaves open the question of how this transformation occurs, unless we consider his general discussion of association, and, what is more, he does not even raise the question of the nature of the "taking into account" of the given conditions of the situation. Thus the question of the basis of perceptual constancy is still open, except that, with regard to the constancy of colour in particular, a factor of "general tint" of illuminance as well as other more or less significant factors which, again, are specific only in regard to *colour* perception and which cannot in any way be regarded as common factors of perceptual constancy in general (except the above-mentioned regularity of the "taking into account" [berücksichtigen] of the general situation to which we shall revert again).

All these valuable observations of the Gestalt psychologists emphasising the importance of taking into account the objective situation in the integral structure of perception are essentially a *description* of that objective regularity which has been repeatedly noted in daily and experimental observation (12, 10) and are not an explanation of the phenomenon, i.e., of the fact that perception is constant when it reflects the situation in which the given object is located and is non-constant when the perceived object is perceived isolatedly ("severed") from the situation. But what is the mechanism of this phenomenon? How does this "taking the situation into account" occur? This question the Gestalt psychologists fail to answer.

The conditionality of magnitude-perception constancy on the object's constituting a component of the situational structure, i.e., the decisive importance of the object being presented in a corresponding situation, i.e., a situation of perceptually "taking into account" was shown in Boring's rigorous experiments (2, 10) and was confirmed in a different experimental situation observed by us (19), but the question of the psychological "mechanism" of this regularity, i.e., of *how* direct perception "takes into account" the given situation without the participation of processes of intellectual nature, remains open.

4. The proposition, current in modern psychology, both in the Soviet Union (Rubinstein and others) and abroad (W. Stern and others), that the common basis of constancy is the intersensory nature of perception, i.e., the circumstance that in the process of activity the single integral personality (concrete integral individual) perceives the object by utilising a complex of sensations of different modalities so that the process of perception of the object is attended with mutual correction of the data of different modalities (for example, the size of the retinal image is corrected by the degree of convergence and accommodation of the eyes and kinaesthesia of the hand and locomotion, etc.), is undoubtedly correct. Without mutual control of modalities there can be no question of perceptual constancy. But so far this conception is limited only to the general proposition without attempting to reveal the concrete psychological "mechanism" of perceptual constancy, to give an analysis of concrete types of constancy or to show that *all cases of constancy are conditioned by an intermodal unity of perception*.

5. J. Piaget, who also solves the problem of constancy of size and form in the aspect of intermodal unity of the subject's activity with regard to surrounding objects (although in doing so he does not emphasise the factor of unity of personality), attempts to reveal also the concrete "mechanism" of the constancy of magnitude and form perception with the aid of an analysis in depth of the process of active interaction with the surrounding world (processes of adaptation and assimilation); the perception of objects takes shape (in childhood) in a process of continuous practical interaction between the subject and the object. The object is perceived not in some one of its aspects

and/or in some one particular modality, but in the process of continuous activity of the subject in space, in a number of *successive* perceptions. The object is perceived in the process of manipulations to which it is subjected visually, tactually and motorially. In the process of these successive perceptions "adaptation" of the subject to the situation takes place. This adaptation implies an equilibrium of two factors—on the one hand, the subject "assimilates" the objects by incorporating them into the "schemes" of his actions, on the other hand, "accommodation" takes place: the object influences the subject, changes the scheme of his actions, his behaviour, the schemes of the subject's actions adapt themselves to the object (26).

Perception taking shape under such complex conditions is not "pure reception" of the object, i.e., is not the image of this object received ("centred") only in one aspect. (Such a purely receptive image of the object, if it does arise, is always non-constant!) Perception is an "applied" or a "practical scheme", a "sensorimotor scheme" or a "perceptual scheme". This scheme potentially ("virtually") contains the relations both between the properties of one object and between different objects (26). These potentially given relations supplement the really, actually given relations in the perceived image of the object. This unity of both these types of relations is the "perceptual scheme" or the scheme of perception, which is constant because it is independent of "pure reception", of fortuitous, changing aspects of perception. The scheme of perception contains the unity ("integrity"—totality) of such perceptions as may be realised only in the process of successive perceptions of the given object, realised in different aspects and in different modalities. These schemes have a sensorimotor content. They are "constructed" not in a process of passive contemplation, not in a process of mediation, but in a process of the subject's vigorous activity, in a process of active, practical interrelations between the subject and the object.

Real perception consists in more than a one-sided image of the object seen in one aspect, i.e., more than "pure reception" of the object.

Despite the incontestable correctness of this observation (in the final analysis it asserts what Professor Rubinstein aptly expressed as follows: "We see the tactual properties

of the object"). Piaget's profound analysis, revealing the process of acquisition of experience with regard to the constant properties of the object, leaves open the main question, namely, in what form does the constant "scheme of perception" exist in the given non-constant "pure reception" and in what form—in the form of what psychological content—is this constant scheme (which has arisen in the practice of successive sensorimotor perceptions) given? Helmholtz also spoke of acquisition of experience with regard to perceived objects, but he could not find the form in which the result of this experience is actualised in one-sided perception, and he had to resort to fallacious concepts of unconscious judgements.

How is a sensorimotor scheme, i.e., the relations which at the given moment are actually not perceived, *and reception that is not pure given in the non-constant, immediate image?*

As far as we know Piaget himself did not raise this question. His analysis of the process of acquisition of appropriate experience on the basis of phenomena of "centration", "decentration" and "regulation" does not go beyond revealing the mechanism of acquisition of appropriate experience with regard to successively perceived objects. Essentially, however, Piaget does have an answer (even two different answers) to this question.

First, he repeatedly emphasises that "pure reception" evokes the entire sensorimotor scheme as a "part evokes the whole" because a scheme is a whole which incorporates two kinds of relations—actually given in "pure reception" and given in potentia (virtually). But such conception of the integral nature of sensorimotor schemes does not in any way explain in the form of what psychological content this constant scheme is given.

Secondly, a more direct answer to the above question is Piaget's other assertion (particularly clearly developed by him in his "L'Epistemology genetique"); he holds that the actual perception *signifies* the meaning of the sensorimotor scheme (25). The "dynamic" (or mobile) or active importance is signified in its direct sensory presence. Thus the *directly given image is that which signifies and the constant content is that which is signified.*

Such conception of constancy *contradicts the immediate character* of perception and bears the stamp of intellec-

tualism, as opposed to Piaget's above-mentioned conception (the signifying function is a function of an intellectual order, however that author may try to specify this "signification", deny its "symbolism", etc.) and thereby contradicts the data of Piaget himself and his associates on the development of perceptual constancy at the age of 6 months and generally the data on perceptual constancy at lower stages of onto- and phylogeny. But even if we recognise in the signifying function of perception a peculiar type of signification the function of signification still cannot explain how the changeable actual perception can by "signifying" evoke a *sensorivisual image* of the constantly perceived object.

Thus Piaget's plausible theory also failed *completely* to surmount the difficulty with which all modern theories of perceptual constancy are faced, since they have no concept which could make understandable the "taking of the situation into account" or the given "constellation" and past experience, specific of the constancy of perception, *without the participation of intellectual processes in perception*. Yet such "taking into account" of the situation and the past experience is noted by representatives of all theories of perceptual constancy and is in fact objectively the most specific characteristic of constant perception.

6. Soviet psychology has repeatedly advanced the proposition on the object conditionality of perceptual constancy. As far back as 1936 Kravkov (18), in setting forth the data of T. Kramer, casually noted that an indispensable condition of "transformation" of colour is apparently perception of the colour of isolated objects, and backed this consideration by an observation according to which the constancy of colour perception decreases together with the decrease in the object perception in lateral vision (18).

In his "General Psychology" published in 1940 (32), D. Uznadze reduces constancy to the general regularity of the influence of the "object" of perception on its "sensory content"; he had substantiated this regularity experimentally in his study "On the Understanding of Meaning" in 1925 (31). In his experiments the subjects with their eyes shut had to recognise by touch the objects placed in their hands; while doing this, they had to reason aloud. There were cases where the subjects called the

properties of the object they felt before finding out what the object was and sharply changed their judgement concerning these perceived properties of the object after "recognising" the object, these properties now being felt in accordance with the "recognised" object. For example, the underside of the object which the subject felt from all sides was perceived as cold and hard, but when the subject decided that he was holding in his hands a round seal, the underside of the object was perceived as made of rubber, softish and not cold. As a matter of fact it was a sealing-wax seal with a cold and hard (copper) underside. Thus the properties of hardness and coldness felt by the subject changed, while the subject felt it, under the influence of his certainty that he was holding an object with a soft and not cold rubber underside.

Asserting that perceptual constancy is conditioned by its objectness D. Uznadze proceeds from the well-known data of D. Katz's classical experiment (12), according to which the constantly perceived colour of objects is perceived non-constantly when the colour is viewed through an opening in a screen, i.e., in the perception of so-called "plane" colour ("Flachenfarbe") or depth colour ("Lochfarbe") and not surface colour ("Oberflachenfarbe").

These most important data furnished by D. Katz are usually interpreted, as that author does himself, as an index of the significance of the entire illumined field of percepiton for perceptual constancy; perception of a small area of colour is always non-constant, since in this case the "general tint" of luminance, etc., cannot be taken into account in perception.

D. Uznadze interpreted these data differently: in usual, direct vision colour is perceived as the colour of the object ("surface colour", according to Katz) and is therefore perceived constantly, i.e., in accordance with the object, but when viewed through an opening in a screen the same colour is sensed as "depth", objectless colour, i.e., the sensation of colour is *deprived of objectness* and is therefore also deprived of constancy.

In the book "Studies in the Psychology of Perception" (29) S. L. Rubinstein developed the proposition that perceptual constancy is conditioned by the object of perception. He advanced the same proposition in his "Fundamentals of General Psychology". The dependence of perceptual

constancy on the *realisation* of the object importance of that which is perceived is investigated in Bein's experimental work published in the same book (1).

But even the objective conditionality of perceptual constancy cannot, of course, of itself be considered an explanation of its mechanism.

That perceptual constancy is conditioned by practical interrelations between the living being and his surroundings is, of course, incontestable. A living being develops an ability to perceive stable, real properties of the object, with which he establishes practical relations, and not the seeming, illusory qualities which change in accordance with the character and intensity of the luminance, distance from the object or perspective in which it is perceived.

But the main problem is precisely how such constant perception of real colour/form and magnitude of objects takes place under such changes in luminance, distance, etc., when the purely sensory reflection of these properties must change in accordance with these changed conditions—changed intensity or colour composition of the light, size or form of the retinal image of the object, etc.

In other words, the question of *how* the object of perception conditions the perceptual constancy of its properties remains open.

As for man in particular and the *realised* objectness of that which is perceived, there are many cases where the constancy of perception is conditioned by an *awareness* of the real state of affairs, a *knowledge* of the actual colour or size and form of the thing, etc. Such observations have been mentioned in literature and a number of similar observations has also been made by us (22).

But, to begin with, to point out the awareness of the real properties of an object is still far from explaining constancy. The knowledge or awareness of the real properties cannot in any way change our perception. In experiments with set we know very well that in critical experiments we take into our hands equal balls or see in a tachistoscope equal circumferences, yet many times running we perceive them as unequal; or despite our knowledge that the earth revolves on its axis we clearly perceive the sun setting behind a mountain or into the sea.

Secondly, there are comparatively few cases where constancy is based on *realisation* of the object's real prop-

erties. In most cases perceptual constancy is of an immediate character, is not anticipated by a realisation of the corresponding properties of the object and manifests itself with regard to *unfamiliar* objects or objects which do not have a specific constant colouring or size. What, then, conditions perceptual constancy in such cases?

Thirdly, and this is the most important, *the fact of constancy of perception at the lower stages of phylo- and ontogeny excludes the possibility of reducing constancy to the realisation of an object.*

As for the unrealised "objectness", its psychological nature has to be revealed; the question of the "mechanism" remains open.

2

Examination of theories of perception constancy brings us to the conclusion that, despite their great variety and the fundamental differences between them, all the theories of constancy are faced with the same difficulty, characterised by incompatibility.

On the one hand, all modern theories based on experimentally established facts recognise that the essence of the phenomenon of perceptual constancy consists in *"taking into account the objective situation"* in which the object is perceived. This regularity cannot be doubted since the classic experiments in constancy of colour perception were conducted by D. Katz (12) and partly by A. Gelb (7), and Boring's experiment (10) in magnitude constancy (incidentally, the results of this experiment were also confirmed under different conditions of our experiments) (19).

As is well known, in these experiments both colour (D. Katz) and size (Boring) are perceived *constantly* when the given object (both familiar and *unfamiliar* to the subject) is perceived in a *segmented* situation and *non-constantly* when the object is perceived outside this situation, severed, isolated from the situation. (In our experiment *non-constant* perception takes place also in *binocular* viewing through a slit of an apparatus when the objective spatial situation is perceived as *unsegmented,* "flattened") (19). In a word, constant perception rests on *"taking the situation into account".*

But, on the other hand, the incontestably established fact of the existence of constancy of perception at lower stages of phylo- and ontogeny absolutely excludes the possibility of reducing constancy to a *conscious intellectual taking of the situation into account.*

It is these two facts—the "taking the situation into account" in the phenomenon of constancy, on the one hand, and the unrealised, non-intellectual character of this "taking into account", on the other hand—that create the incongruity which all the theories are unsuccessfully trying to overcome. *How does this "taking the situation into account" resting on the subject's past experience take place without the participation of conscious intellectual processes?*

We believe that the concept which makes it possible to overcome this collision and most closely approach the solution of the problem, to interpreting the *unrealised* "taking the situation into account" is the concept of *fixated set* as conceived by D. Uznadze (33). We assume that set is the factor which conditions an *organisation of perception corresponding to the objective situation,* in other words, conditions the "taking of the objective situation into account" *in the form of an organisation of perception corresponding to this situation,* i.e., conditions constant perception corresponding to the situation without the participation of conscious intellectual processes. This assumption is based, first, on the repeatedly *experimentally-demonstrated and well-established fact of the change in the sensory content of perception, particularly of the size, colour and form of objects under the influence of appropriately directed set,* fixated set in particular (23), such manifestation of set *not at all requiring the participation of intellectual conscious processes, particularly observed at lower stages of phylogeny* (in simians, dogs, rats, hens) and ontogeny (in children) (33), and secondly, on the fact that the most essential characteristic of set, according to the above conception, is that this is a state of a definitely directed readiness of the subject, *is conditioned by the objectively-given situation* (33).

On the basis of such properties of set it is natural to assume that, as a result of phylo- and ontogenetic development in the process of practical interaction with objects under different conditions of perception, living beings have elaborated a definite set for real objects and their constant

properties which do not depend on chance conditions of perception. And, if this is so, it is clear that under the influence of this set, for example, the colour of these objects is perceived within certain limits constantly, i.e., to a certain extent independently of the intensity of the given illumination. *Set "takes into account" the objective situation, without intellectual processes,* for example, it takes into account the degree of general illuminance or its general "tint", since set is determined by the given situation. It is natural, for example, that in intensive overall sunlight black and white objects are perceived as black and white, as they are under weak lighting, since the general set for the brightness of lighting of the entire sitution changes correspondingly, *regardless of whether we realise it or not;* it is not necessary to draw any conclusions about the change in colour as a result of the change in the intensity of lighting.

The main result of D. Katz's investigations—constancy of colour perception in direct viewing and non-constancy (loss of constancy) in its perception through an opening in the screen—is quite natural from the point of view of the action of set. In the former case the objects are perceived with a set for the general situation in which the lighting is less bright in the part of the field of vision where the second object is located. In the latter case perception is non-constant because both objects are perceived in isolation from the illumined situation which is screened, and the colour of the objects is therefore perceived independently of the lighting, only in accordance with the light reflected from them and without objective relation of colour.

Quite natural from the point of view of the manifestation of set are also the daily-observed facts when, being of the very same size in the retinal image, an object is perceived larger or smaller depending on its distance from the subject. For example, the very same objective thing moving along a window-pane is perceived larger when you perceive it as an object moving in the sky (i.e., with a long-distance set) or as tiny when you perceive it moving along the window-pane, i.e., with a short-distance set.

A bit of fluff hanging from the brim of your hat is perceived by lateral vision as an enormous cloud in the sky, but when your surprise (you have just admired a cloud-

less sky) destroys this set you perceive the same object as a bit of fluff no larger than 1 cm.

The use of the concept of fixated set is also appropriate in interpreting the nature of the constant mental structure which J. Piaget named a "scheme" of perception that is formed, according to that writer, as a result of a number of successive perceptions of the given object. As was mentioned above, Piaget reduced to this scheme of perception the essence of the phenomenon of constancy. Use of the concept of set would have freed the author of the necessity of unjustifiably assuming a relation of "signification" between non-constant "pure reception" and a constant "scheme". Constant perception is developed on the basis of *fixated set* developed in the process of the subject's sensorimotor experience.

Use of the concept of set is also very appropriate in interpreting the influence of awareness of an object on its perception; awareness of an object may produce in us a corresponding set which accordingly modifies our perception (of course, for the emergence of a corresponding set it is not always enough to become aware of the object of perception, especially in cases of already fixated set). To overcome an already fixated set, awareness of the object does not usually suffice (24).

The above results of D. N. Uznadze's experiments (31) must obviously also be conceived as the influence of the set conditioned by the object of perception on the sensory content of the thing perceived; the perceived tactile qualities changed in accordance with the object implied by the subject precisely because this implied object evoked in the subject a corresponding set. In daily life such phenomena—changes in the perceived properties (for example, colour) of the object in accordance with the changes in the object implied in perception (for example, in recognising an object in the twilight)—are observed quite often.

Use of the concept of set is also fruitful with regard to the old problem of the binoculars and the magnifying glass; in the case of the binoculars the perceived image leaves the impression that the objects seen have been brought closer, the looking through the binoculars creating a long-distance set (the situation often involves objects of sizes which are unknown to the subject and are many kilometres away—trees, hills, buildings, etc.) and an enlargement of the retinal

image is therefore perceived as *approximation of the objects*, while a diminution in the retinal image is perceived as recession.

When viewed through a magnifying glass the entire situation, on the contrary, creates a set for *enlarging* the object which remains the same short distance away: the extremely short distance (a few score centimetres) from the object viewed through the magnifying glass is continuously fixed by direct contact of the hands with the plane in which the object is located. Against the background of such a set the enlargement of the retinal image is perceived as an *enlargement* of the object and not as its recession.

An analogous phenomenon occurs in cases of illusion of size perception in a heavy fog or in an unfamiliar or barely familiar place. When, for example, a person who is on a mountain top finds himself in a cloud, he perceives some objects at first several times as large as they really are. The foggy "air perspective" apparently produces a long-distance set for the given objects, and since their retinal images are large (because the objects are objectively very close) the objects are perceived as huge as they should have been, if, located far away, they produced such large retinal images as they do at the given moment. But as soon as the set for distance has changed, as soon as the person treats the objects as located closely (this happens for various reasons—the person recognises the place, or a familiar object appears next to those being perceived, or the person recognises the objects, etc.) the sizes of the objects instantly become normal.

It should be noted that facts incontestably in favour of the importance of the factor of set have been repeatedly established during the history of the studies of perceptual constancy.

Enumerating the factors which condition constancy, D. Katz, who collected extensive and diverse material on constancy of colour perception, notes the factor of set (Einstellung); it turns out that his subjects with a "critical set" or a set for "pure optics" (Einstellung auf rein Optik) perceived colours non-constantly when seen directly without a screen.

The role of the "direction" of the subject's perception (called "inner set"—"innere Einstellung" [A. Gelb] or "intentional set" [Brunswik's school]) in the process of

constant or non-constant perception has been repeatedly demonstrated in the history of the studies of perceptual constancy. As far back as 1930, W. Köhler asserted that it was possible, after acquiring appropriate experience, to perceive an object both in the given situation (in the structure of the given field of vision) and therefore constantly, and in isolation from this situation and therefore non-constantly.*

Special experimental studies of the role of such direction called "intentional set" in constant or non-constant perception of size and form (16) have been coducted under Brunswik's supervision; if the "intentional set" is directed toward the "real" size or form of the object, the size (or form) is perceived constantly, but, if this set is directed toward a "phenomenologically" or "projectionally" given size (or form), the perception is non-constant. An analogous result was obtained in the well-known studies conducted by Thouless (30).

But in these works the concept of set is used as a concept expressing the *direction* of the subject's perception, his goal-directedness, and not as an explanatory concept revealing the "mechanism" of perceptual constancy (compare, for example, with Brunswik's theory) (3). It merely indicates *toward what* perception is directed, *what* the subject aims to perceive, for example, the size of the object or the "projectional" size (Brunswik and others), or the entire structure of the field of vision or an isolated object (Gestalt psychology), etc.

We are faced with a different problem. Since we assume that set is one of the factors determining constancy of perception, *factors appropriately organising our perception on the basis of the subject's past experience,* we are faced with the problem of experimentally checking on the factor of *fixated set* in constant perception and not on the role of the direction of perception, attention or conscious aim— to perceive the real size of an object or to be limited to the direct impression corresponding to the retinal image of the object.

* In the English version of the book *Gestalt Psychology* (15) he points to "attitude" as the determinant of these two directions of perception, while in the German version of the same book (*Psychologische Probleme*, 1933) he speaks about different behaviour ("Verhalten") of the subject.

In the first place we decided to reveal the manifestation of set fixated for a definite situation in the process of perceiving the size of the object.

We have conducted a series of experiments whose methods and results have been published (19; 21).

METHOD

With a view to experimentally studying the above problem, this writer designed an apparatus (a modified type of Hering's apparatus [a 1 m long truncated pyramid resting on its side] for monocular perception of space) which enables exposure in its inner space of small balls of different sizes suspended from the "top" of the device at different distances from the subject's eyes, and to change the conditions of perception in such a way as to evoke at will in the subject various degrees of constant or non-constant size perception of the exposed objects. This is achieved in the following way.*

1) When the subject looks (monocularly) through a peep-hole in the front wall of the apparatus, or through a cone-shaped tube attached to the peep-hole, he perceives the balls which are suspended in the apparatus in a highly "flattened", almost non-articulated perspectiveless position; thus, his perception is non-constant.

2) Almost the same degree of non-constancy of perception is obtained in the case when the subject looks *binocularly* through a narrow slit in the front wall of the apparatus; here the perceived space is somewhat widened only in the horizontal plane (to the right and to the left); but since the apparatus has no side walls, the very slight articulation and "flatness" of the perceived space show negligible increase.

3) When a special shutter is pulled out of the front wall of the apparatus, it becomes possible to perceive the space through a rectangular window (18×8 cm); because of this, perception of the situation becomes so articulated that the subject, as a rule, perceives the balls in a *constant* way, according to their distance from the window.

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* For a detailed description of the device see (19.)

4) Finally, removal of the entire front wall of the apparatus results in the balls being perceived with a still greater degree of constancy and in a still more articulated situation (19).

PRELIMINARY EXPERIMENTS

The objective was to fixate in the subject a set for a perspectiveless, "flattened" spatial situation by means of repeated (more than 20 times in succession) perceptions of balls through the peep-hole or slit ("set-inducing" experiments), and immediately after such fixation, to make the subject perceive the same balls through the window ("critical" experiments), i.e., in the same conditions under which the subject's perception of objects in the course of control experiments is constant.

If "appraisal of the situation" is effected by means of a set which organises a corresponding perception, then a set, experimentally fixated for perspectiveless "flattened" situations, must result conformably to that situation, in *non-constant* size perception of the objects during the first "critical" exposures through the window; and only later, after extinction of the fixated set and transition to another set (adequate to the new, differentiated situation), perception of the objects through the window must become *constant*.

Three variants of preliminary experiments and two variants of the basic experiment were carried out.

1. In the course of the first variant of preliminary experiments two small balls were exposed; one 16 mm in diameter was suspended at a distance of 85 cm, and the other of a diameter of 12 mm was suspended at a distance of 40 cm. The duration of the exposure was 1 to 1.5 sec. In all, 22 exposures were made; in the first 12 exposures the larger ball was suspended to the left of the small one, and in the last 10 exposures, vice versa (i.e., the larger ball was suspended to the right of the smaller one). All the 9 subjects perceived the more distant (objectively larger) ball as being the smaller one; thus, their perception was non-constant.

After 22 "set-inducing" exposures (with viewing through the peep-hole or slit) the Ss directly passed to perception through the window, i.e., to the "critical experiments", in other words, to perception under such conditions where

the subjects perceive, without preliminary set-inducing trials (i.e., in the control experiments), the balls in a constant way. In the course of the first critical experiments 7 subjects (out of 9) manifested *non-constant* perception (they perceived the more distant ball as being the smaller one or equal), and only in the course of subsequent experiments six of these subjects began to manifest constant perception (one—after 15 exposures; one—after 8 exposures; one—after 7 exposures; one—after 3 exposures; one—after 2 exposures, and one—after 1 exposure). As to the seventh subject, he did not manifest any transition to a fully constant perception; the balls were perceived by him as being equal as long as the front wall of the apparatus was unremoved.

2. In the course of the second variant of set-inducing experiments *equal* balls (16 mm in diameter) were exposed at different distances (41-24 cm, 57-30 cm, 41-27 cm).* During the first 12 exposures the more distant ball was suspended to the left of the nearer ball, and during the last 10 exposures—to the right of it.

In the course of the set-inducing experiments, i.e., while viewing through the peep-hole, all the 12 subjects manifested non-constant perception (the more distant ball was perceived by them as being the smaller one).

In the course of the first critical experiments, i.e., while viewing through the "window", 10 subjects (out of 12) continued to perceive the balls non-constantly (the more distant ball seemed smaller to them), although the objective conditions were the same as in the control experiments when their perception of the balls was constant. Subsequently, 8 out of the 10 subjects began to manifest constant perception in accordance with the new situation. In 4 of them the transition to constant perception was of a gradual character (after four, two, and one exposures): the difference in the perceived size gradually diminished until the size of the balls became equal; the other 4 subjects passed to constant perception abruptly, though also after several exposures.

Two subjects (out of the 10) did not pass to constant perception at all until the front wall of the apparatus was

* These are distances from which the subjects in the course of the control experiments perceived the balls in a constant way when looking through the "window".

fully removed, i.e., until the objective situation became articulated to the greatest possible degree. Apparently, a very stable fixated set is characteristic of these subjects.

Thus, in the second variant of experiments (with equal balls in the critical experiments) in only 2 subjects (out of 12) the set fixated for a non-articulated situation was not manifested: apparently, no *fixated* set had been evolved in them at all or the set evolved was so weak and unstable that it fully disappeared with the subject's first glance at the articulated situation.

3. In the course of the third variant of preliminary experiments *equal* balls (16 mm in diameter) were exposed at equal distances in order to preclude the possibility of a set being evolved for size comparison (as expressed, e.g., in the subject's statement: "To the right is the larger ball"); otherwise, one could assume that in the course of these experiments the set in question was fixated not for a "flat", non-articulated situation, but for size comparison, as practised in the basic experiments of the Uznadze school* (23).

But in the course of the critical experiments (while viewing through the "window"), *equal* balls were exposed at *different* distances, namely, at those at which the subjects during the control experiments manifested constant perception when looking through the window, i.e., when they perceived the balls as being equal (57 and 30 cm; 60 and 30 cm; 41-24 cm).

The following *results* were obtained: in the course of the critical experiments 2 subjects (out of 10) perceived, from the very outset, the balls in a constant way (i.e., as being equal).

In the remaining 8 subjects an obvious influence of the fixated set on perception was observed already during the

* Although several circumstances testify against such an interpretation:

1) the location of the "larger" and the "smaller" balls in the set-inducing experiments, as stated above, changes: the "larger" ball is now to the right, and now to the left;

2) the difference in size of the balls perceived is slight;

3) the illusion is always of assimilative nature, which is seldom observable in course of fixation of a set for size differences; to ensure complete elimination of this possibility a third variant of the preliminary experiments and the basic experiment were conducted by the present writer.

first critical exposures; these 8 subjects perceived the more distant ball as being the smaller one, although they looked through the window, i.e., their perception proved to be non-constant in conditions which were similar to those of the control experiments, when their perception was constant. Thus, the influence of a fixated set on perception in a "flat", non-articulated situation while viewing through the peep-hole is quite evident.

In the course of subsequent repeated critical exposures 6 of the above-mentioned subjects manifested a transition to adequate constant perception, while the remaining 2 subjects showed such a transition only after the removal of the front wall of the apparatus, i.e., in conditions when the degree of articulation of the spatial situation was the highest.

THE BASIC EXPERIMENT

Since in the course of the third variant of preliminary experiments equal balls were exposed at *equal* distances owing to which they were perceived as equal ones, while in the course of the critical experiments equal balls were exposed at *different* distances and were therefore perceived as *different* in size, i.e., non-constantly, it must be assumed that these conditions fully exclude the possibility of a set being evolved for *size comparison*, because the balls presented in the set-inducing experiments were perceived as being equal, whereas in the critical experiments they were perceived as being quite *different* in size.

But to be absolutely sure that the set is fixated for a non-articulated situation, and not for a correlation of sizes, we excluded from the set-inducing trials of our basic experiment all possibility of size comparison; in both variants of the basic experiment we exposed *one* ball (22 mm in diameter, and sometimes 14 mm), thereby excluding any correlation of sizes. But in order to stimulate the subject's active attitude to the perceived object, without which the set could not be evolved, we instructed the subject to memorise the exact size of the ball, warning him that at the end of the experiment he would be asked to draw it on paper. In the set-inducing experiments the S looks through a conical tube attached to the peep-hole of the device, i.e., he perceives under conditions of a maximally "flattened" perspective.

The basic experiment was carried out in two variants which differed only in the following: in the course of the *critical* experiments of the first variant *equal* balls were exposed at different distances, while in the course of the experiments of the second variant balls of *different* sizes were exposed at different distances: this made it possible to establish more exactly the degree of constancy or, conversely, the degree of non-constancy of perception: the more distant ball could be perceived as being smaller, or larger than the nearer (objectively smaller) ball, or as *equal* to it.

RESULTS OF THE FIRST VARIANT OF THE BASIC EXPERIMENT

Eight subjects out of 54 (14. 1 per cent) demonstrated from the very first exposure a constant perception of the balls (they perceived them as being equal), this means that the set-inducing experiments did not exert any influence on the subjects' perception. Four subjects at first produced non-constant perception, and only after several exposures their perception became *constant*; nevertheless, this effect should not be regarded as a manifestation of the fixated set, since these 4 subjects had produced a similar effect in the course of the control experiments. Their first perceptions through the window were of a non-constant character, and only after several exposures there took place a transition to constant perception. Presumably, 12 Ss (22 per cent) of the 54 did not come under the influence of the set-inducing experiments.

If we exclude these 4 subjects too, then altogether in 42 subjects (out of 54, i.e., in 77.8 per cent) in the course of the critical experiments there was observed a clear-cut manifestation, in some way, of a set fixated in the set-inducing experiments for a non-articulated spatial situation.

24 of these subjects (44.4 per cent) produced non-constant perception during the first exposures (from 16 to 4 exposures) and then passed to constant perception—some of them abruptly, some gradually, and some after an alternation of constant and non-constant perception. (For details see [21].)

In 9 subjects there was observed "infinite" non-constant perception, and only after the removal of the front wall

of the apparatus they manifested a transition to constant perception.

In *three of these subjects*, as well as in *three other* subjects (whose perception became constant in the process of their looking through the window), thus (6 subjects. i.e., 11.1 per cent) the *non-constancy* of perception not only did not show any diminishment, but, on the contrary, *increased* in the course of the first 5-11 exposures: the apparent difference in the size of the objectively equal balls (but situated at different distances) *increased* in the course of the above-mentioned exposures. In 6 subjects (11.1 per cent) there was observed a *contrastive* and not *assimilative* action of the fixated set; during the first exposures 4 of these subjects gave evidence of the phenomenon called "superconstancy" (*surconstance*) by J. Piaget (28); the more distant ball was perceived by them as being larger than the nearer, objectively equal ball; subsequently, in the course of further exposures this difference diminished and finally fully disappeared—the balls were perceived as being equal, i.e., in a constant way.

As to the remaining 2 subjects (out of the above-mentioned 6), in whom a *contrast* action of the fixated set was manifested the following phenomenon was observed: in the course of the first critical exposures their perception of the balls proved to be more constant (perfect equality) than in the course of the subsequent exposures and of the control experiments, when they perceived the balls as "approximately equal", "almost equal", or "rather equal". Apparently, to these subjects (in the same way as to the other four who manifested a contrast effect) the articulated situation seemed yet more articulated, and the perspective yet deeper, when they were looking through the window against the background of a set fixated for a "perspectiveless", non-articulated situation and the balls were perceived by them as situated at a yet greater distance from each other.

RESULTS OF THE SECOND VARIANT OF THE BASIC EXPERIMENT

As already mentioned above, the set-inducing experiments of this variant were identical with those of the first variant (presentation of a single ball). In the critical experiments, however, two balls of different sizes were

exposed (12 and 16 mm). Their distance from the peep-hole varied (41-90 cm; 41-85 cm; 24-85 cm and 30-75 cm) but always remained equal to that in the control experiments (i.e., in experiments with no preliminary set-inducing exposures) which ensured the subject's constant perception under conditions of looking through the window (i.e., when the more distant and objectively larger ball was perceived as being the larger one). To 50 per cent of all the subjects the more distant (larger) ball was shown to the right of the nearer ball, and to the other 50 per cent—to the left of it.

The experiment was carried out with 50 subjects.

1. Thirty of them (60 per cent) showed a *strong effect* of the fixated set. In the course of the first critical experiments their perception was absolutely non-constant: the more distant, objectively much larger ball (16 mm in diameter) was perceived as being the smaller one; subsequently, after a number of exposures 24 subjects (48 per cent) manifested transition to quite constant perception (the more distant ball was perceived as being the larger one), and 6 subjects began to perceive the balls as being equal ones, i.e., not in a quite constant way; only after the removal of the front wall their perception became quite constant.

2. In 5 subjects (10 per cent) the manifestation of the fixated set proved to be weak, although the action was typical in its direction: during the first exposures the balls were perceived as being *equal*, and only after several exposures the perception became quite constant, i.e., the more distant ball was perceived as being the larger one.

Thus, in *35 subjects (70 per cent) a set fixated for a non-articulated situation*, was typically manifested—non-constant perception during the first exposures and a subsequent transition to more constant perception.

3. In 3 subjects (6 per cent) the action of the fixated set was also very strong: the perception of the balls was quite non-constant (the more distant ball was perceived as being the smaller one), but this lasted only until the front wall of the apparatus was removed. Thus, in these 3 subjects the fixated set proved to be so stable that it could not be destroyed by the high degree of articulation of the situation as perceived by the subjects when they looked through the window of the apparatus.

4. Twelve subjects (24 per cent) manifested constant perception of the balls already from the very first critical exposures.

Thus, the action of the fixated set in the second variant of the basic experiment manifested itself in 38 subjects out of 50 (76 per cent).

CONCLUSIONS

1. The following findings must be regarded as experimentally established facts: a) emergence of a set for "perspectiveless" perception (when the objects are perceived in a non-articulated situation for, otherwise, such a set would not be susceptible of fixation), and b) in an objective situation, which under normal conditions (in the control experiments) ensures *constant* perception of size, the perception remains *non-constant* as long as it is determined by *a set fixated for "perspectiveless" perception.*

2. Consequently, *"appraisal of the situation" in our experiments is effected by means of a set*: as long as the set which is fixated for a "perspectiveless" situation (i.e., the set which "takes into consideration" the distribution of objects in a "flat" situation) continues to act, perception, *in accordance with this situation,* proves to be *non-constant.* An objectively articulated situation cannot be "appraised" in the process of perception until there emerges a set which corresponds to it, i.e., a set for an articulated spatial situation, for a perspectival perception of objects. In our experiments this occurs when the set fixated for a "perspectiveless situation" becomes "extinguished".

3. Thus, "appraisal" of a given objective situation, which determines the constancy of size perception (in particular, perception of an object in an articulated spatial perspective) takes place *only when a set corresponding to that situation emerges in the subject*; but if we exclude this set and *replace it by a set which is not adequate to the given situation size constancy becomes disturbed*—the perception proves to be *non-constant until this inadequate set gives way to another set which is adequate to the given objective situation.*

* * *

Consequently, it is to be assumed that *a set corresponding to the given objective situation* is an important factor in the "mechanism" of constancy of perception; *a "mechanism" determining the unconscious "appraisal of the situation" which, according to most present-day investigations, is responsible for the constancy of perception.*

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CONCERNING TIME PERCEPTION AND THE FEEDBACK PRINCIPLE

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The psychology of time perception is increasingly attracting the attention of investigators, although very little is as yet known about a number of mechanisms by means of which this reflective activity is carried on.

In a number of experimental studies we have succeeded in showing that perception of rhythmic stimuli is characterised by a certain *motor accompaniment* consisting in movements of the head, trunk and most commonly the extremities. This motor accompaniment is tuned in unison with the acting stimulus, which is expressed not only in the corresponding speed, duration of separate movements and pauses between them, but also in the motor accent which corresponds to the accent in the perceived group of stimuli (6), (8). The *motor accent* consists in a stronger or weaker, longer or shorter movements than the others. which somewhat sets it apart from the rhythmic complex of movements. The motor accompaniment also takes place when the acting stimuli deprived of rhythmic characteristics are rendered subjectively rhythmic (12).

The "combined motorium" (A. R. Luriya) which characterises the reflection of the rhythmic stimulus has a certain architecture. The experimental material collected by us attests that the movements of the extremities, the arms in particular, which accompany perception of the rhythmic stimulus are of a bilateral character. The leading role in the motor accompaniment of rhythm is played by the right arm which by its movements seems to reproduce the general pattern of the rhythmic complex: the succession of beats and pauses between them. The left arm plays an auxiliary role: it accents one of the members of the rhythmic series about which all the others are grouped.

Coinciding with the movements of the right arm in the beginning of the rhythmic series the movements of the left arm strengthen the perception of the initial stimulus and the one which acts as the accent in the rhythmic group. This is attested by the oscillograms recorded by us. It is also attested by the kymograms of the movements of the right and left arms we have recorded by means of special keys (6), (12).

The combined motorium also incorporates the movements of the lower extremities and trunk, which emphasise the various features of the accompaniment of the arms. In cases of inhibition of the latter they become more distinct and assume an independent character; in these cases the lower extremities perform the functions of the upper extremities, only with somewhat lesser effect.

Analogous phenomena occur when the upper and lower extremities are excluded. In this case the motor accompaniment is carried out by the head and trunk. Under the aforesaid conditions the structure of the combined motorium somewhat changes, although essentially retaining the aforementioned features. This consists in the fact that one of the movements strictly follows the general motor pattern of the rhythm, reproducing the succession of the sound stimuli, the duration of each of them and the pauses between them, while the other movement serves to designate the accent which is a characteristic component of the rhythmic series (7). The foregoing picture of the motor accompaniment somewhat resembles the motorium of the hands in bimanual palpation ascertained by B. G. Ananyev and his associates (1).

To be sure, there are individual cases where the spontaneous motor accompaniment assumes a monolateral character. Under the conditions of this type of motorium the perception and reproduction of the rhythm become worse and somewhat incommensurate with the acting series of rhythmic stimuli (13).

The motor accompaniment under consideration serves as an additional source of afferent signals received by the cerebral hemispheres as feedback, which is a necessary prerequisite for an adequate reflection of objective stimuli.

That is why, as T. M. Kozina has shown in our laboratory, the disturbance in the unison of the motor accompaniment, which is easily effected under experimental

conditions, leads to incorrect reproduction of the rhythmic group of acoustic stimuli: they are reproduced in accordance with the disturbed accompaniment and not with the perceived rhythmic series (16).

What is the significance of the motor accompaniment in time perception?

A number of data accumulated in our laboratory over a period of years show that under conditions of reflecting the temporal parameters of the stimulus the combined motorium performs two functions.

1. Tuning up in unison with the stimulus it models it in a certain manner, reproducing the rhythmic succession of stimuli, the motor accompaniment being an important condition for correct perception and reproduction, which are corrected by signals coming to the brain as feedback from the motor apparatus.

2. Acting on the cerebral hemispheres as a subdominant stimulus the combined motorium increases the activity of the dominant focus connected with the reflection of the peculiarities of the stimulus.

This is attested by N. V. Ogorodnikova's experiments conducted in our laboratory.

She studied a number of processes in the subjects—motor coordination, precision of movements, dynamometry, the absolute threshold of tactile sensitivity, estimation by sight under usual conditions and under conditions of rhythmic stimulation (300 beats of an electrometronome per minute). It turned out that the rhythmic stimulation improved the coordination of the movements, made the motorium more precise, increased muscular power, reduced the thresholds of tactile sensitivity and enhanced the precision of the estimation by sight.

An analogous experiment was conducted in industry. The productivity of labour of a group of female workers packing ampules in an Odessa chemopharmaceutical factory was studied under usual conditions.

The motor accompaniment, as was established by a number of studies, may be replaced by a corresponding motor concept which performs the functions of combined movements, imparting considerable precision to the time perception. The latter is somewhat lower than the precision of reflection of the stimulus under conditions of combined motorium, but higher than the precision

observed in the absence of movements and ideas of them (9).

In complete conformity with the suggested propositions are our data which indicate that the kinaesthetic analyser reflects time more precisely than the cutaneous and visual analysers (9).

It should be noted that the productivity of time perception in the activity of the other analysers (for example, the cutaneous analyser) is in large measure determined by the participation in this activity of motor processes in the form of a motor accompaniment.

Thus Kozina has established in our laboratory that cutaneous perception of the speed of a moving mechanism wins under the conditions of motor activity of the fingers which were in contact with this mechanism. These contacts are accompanied by the subject's general motor activity which is tuned in unison with the rate of the movement of the mechanism. The reflection of speed loses in precision in cases of disorders of this motor accompaniment (9).

That is why, as our clinical observations show, the injuries to the motorium in hemiplegias, diseases of the cerebellum, are characterised by disturbances in time perception, which manifest themselves in considerable errors of reflection of the duration and succession of the acting stimuli (9). A particularly clear picture of pathology of temporal perceptions may be observed after survival from encephalitis, as a result of residual phenomena, constraint of movements and tremor which are often responsible for the complete disorganisation of the reflection of duration and succession of the stimuli (9).

The motor accompaniment of temporal perceptions, which is the source of return afferentation, may be of a visceral character, expressing itself in corresponding changes in respiration, cardiac activity and filling of the vessels with blood. This is attested by the works of the French psychologist M. Pavlov and our experimental studies which demonstrate a certain relation between the peculiarities of time reflection and the character of pneumo-sphygmo- and plethysmograms (30), (11).

We have succeeded in showing experimentally that there is a certain relation between the perception of the duration of the stimulus and the peculiarities of pulsation of the radial artery: the greatest precision of perception is

observed at typically human 72-84 beats of the pulse per minute. The greater the deviation from this pulsation, the greater the error in time reading. The character of the error also bears a certain relation to the character of the deviation from the usual pulsation: with a deviation of the number of pulse beats in one direction an error in time perception is observed with one sign, with a deviation in another direction an error with another sign is observed. We may therefore speak of the existence of a "visceral clock" which participates in the reflection of time. Some people feel time most precisely during normal and pathologic sleep (3, 5, 11).

However, the visceral motorium is characterised by slight mobility, for which reason its possibilities of tuning in unison with the acting stimulus are somewhat limited. But it would be wrong to deny all variability of organic movements under the action of external stimuli.

Following our experiments (9) N. V. Ogorodnikova showed by means of electrocardiography that the speed of propagation of excitation changes under the influence of different rates of rhythmic stimulation—it is higher than at a slow rate of stimulation (27), (28), (29). At the same time the dynamics of the visceral motorium are very much inferior to the somatic movements which are more supple and responsive.

We have made an experimental attempt to elucidate the role of these movements in the modelling of time. By means of a vibrator of our construction we communicated motor impulses to the subject's lower extremities every 3″ and 5″. We did it daily for a long period, in some cases for close to one month. The vibration signals received by the subjects considerably improved their time reading: the 3″ and 5″ intervals which ordinarily accounted for considerable errors were reproduced almost unerringly after the experiments with the vibrator.

It may be assumed that an important role in modelling time is played by customary activity—walking, speaking, occupational motor habits, etc. (9). In many cases this activity may be replaced by ideas, i.e., may assume the character of "mental activity" (L. S. Vygotsky, A. N. Leontyev, P. Y. Galperin) which retains modelling and regulatory functions (18).

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The surrounding conditions, education, occupational activity and labour training, musical studies, physical culture activities and creative processes in a certain measure alter, exercise and reorganise the motor accompaniment and in some measure contribute to the differentiation of time.

In our laboratory L. Y. Belenkaya studied with the aid of a telegraph key the character of motor reactions of 80 schoolchildren of the first and fourth grades. The children were divided into fast-reacting and slow-reacting subjects. By organising the labour training under conditions of a strict time regimen it was possible to produce certain changes in the children's motor functions. Together with the teachers the experimenter tried to impart considerable rhythm to the labour lessons by avoiding chance interruptions and irregularities, and by ensuring timely preparation of materials, samples, etc. Detailed synopses of the lessons listing all the labour operations in a definite succession and indicating the time of performance of each of them were elaborated. The pupils knew that they had to guide themselves strictly by the time regimen and finish work at a very definite time.

As a result of this organisation of labour training which lasted several months the differences in the speed of the motor reactions between the two groups of pupils diminished: the fast-reacting pupils exhibited a slower reaction than they had before the labour training and the slow-reacting children—a faster reaction (2).

The speed of the reactive movements of the two groups of subjects who were tested after the labour training was almost equalised, having undergone considerable changes under conditions of a training regimen organised in a certain manner. It is noteworthy that observing the established time regimen at the lessons the pupils unerringly oriented themselves in it with the result that the training proved more effective.

In our laboratory N. V. Ogorodnikova and V. D. Zmiyenko conducted an experimental study to reveal the ways and means of making good the lag in the development of perception and reproduction of rhythm in a group of music school pupils who because of this lag made slow headway in music. Their main shortcoming was that they

played faster or slower since they could not play without counting aloud and were unable to reproduce a simple rhythmic pattern.

To reveal the peculiarities of rhythm perception, the subjects were tested every two weeks: they had to reproduce by hand movements from 44 to 252 rhythmic beats of an electrometronome per minute.

To train their sense of rhythm, the subjects were given several times a week special rhythmic exercises with a musical accompaniment, according to a certain programme to 4/4, 3/4, 2/4, etc., time. As a result, the perception and reproduction of rhythm improved, which in its turn contributed to considerable progress in the musical training.

The shortcoming manifested in faster or slower playing disappeared and ceased to affect the normal musical development of the pupils (40).

An analogous experiment with other material was conducted by T. N. Fedotova. The experiment was aimed at studying the regularities of perception of poetic rhythm, perception of poetic meter by schoolchildren. The subjects who had poorly oriented themselves in complex poetic meter (dactyl, anapest, amphibrach) rapidly mastered it after a number of experimental exercises with an electrometronome. The experimenter demonstrated dactyl, anapest and amphibrach to the subjects by means of rhythmic beats of an electrometronome and made them reproduce complex poetic meter by tapping on a table, which resulted in the requisite motor tuning (14).

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The motor accompaniment of temporal perceptions is characterised by an individual peculiarity which is in large measure due to typological characteristics of higher nervous activity. It may be assumed that this also accounts for certain individual peculiarities of time reflection.

Already A. O. Dolin had made an experimental attempt, approved by Pavlov (32), to establish a connection between certain typological characteristics of man's higher nervous activity and his movements. However, this

study could not be carried out to the end and it was not published.

Our laboratory undertook to elucidate the connection between the mobility of the excitatory process and the peculiarities of the combined motorium under conditions of perceiving a rhythmic stimulus. A. G. Medvetskaya used a group of conservatoire and civil engineering students as subjects. In the experiments it was necessary to reproduce by hand movements 60, 120, 180 and 240 rhythmic beats of an electrometronome per minute. Three series of experiments were conducted. In the first series the subjects reproduced the demonstrated rhythm simultaneously with the metronome, in the second series—after the metronome had been switched off, and in the third series they were instructed to discontinue their movements simultaneously with the switching off of the metronome. The subjects were chosen by extreme typological characteristics—mobility and inertness of the excitatory process.

The resultant data show that the active subjects accelerate the demonstrated rhythm when reproducing the stimuli, while the inert subjects slow this rhythm down; in musicians in whom the reflection of temporal parameters is more adequate this phenomenon is manifested somewhat more feebly (26).

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Second signal connections actively participate in man's motor resonance, which is vivid under conditions of time perception. Man counts, uses various measures, reference points and temporal concepts which ensure the greatest adequacy of reflection both internally and externally (10).

In our experiments perception of the duration of a particular time interval was always accompanied by counting, in most cases in whispers and sometimes in internal speech. Inhibition of the speech accompaniment leads to inadequate reproduction of duration (10).

Kozina succeeded in obtaining in our laboratory a number of oscillograms of speech movements under conditions of perception of duration and succession. These speech movements tuned in unison with the acting stimulus are the source of feedback which together with corresponding comparison corrects the reflective activity.

Inhibition of the speech accompaniment upsets the correctness of perception of the duration and succession of stimuli (21), (24).

These conclusions are attested by a number of observations of patients with clearly marked aphasia. M. B. Shapiro, a worker of our laboratory, has found disturbances in perception of time, particularly in perception of rhythm, in cases of affection of the third frontal gyrus of the left cerebral hemisphere. A female patient with phenomena of motor aphasia was unable to reproduce trisyllabic rhythms—dactyl, anapest and amphibrach—although she had no difficulty in reproducing simpler rhythms—iamb and trochee (9).

There is a certain relation between the development of speech and differentiation of time. L. D. Dragoli found that the more developed the culture of speech (temporal adverbs, temporal forms of verbs, etc.) in children, the more correctly they differentiate various durations, various successions and the speed of stimuli. Proper organisation of children's speech training aimed at increasing the temporal designations they use leads to considerable improvement in time differentiation (4).

V. L. Yaroshchuk used the "method of forming mental action" (P. Y. Galperin) to form various temporal concepts in children of preschool age. This also favourably affected the subjects' time differentiation (39).

Particular importance is assumed by speech feedback in the formation of temporal skills which win a good deal under conditions of verbal information: knowledge of the errors and achievements in elaboration of the automatism of reproduction of temporal intervals is often a necessary prerequisite for their adequacy (39).

Of no lesser importance in the formation of temporal automatisms is preliminary information on the duration, speed and succession of the acting stimuli. Under these conditions the temporal skill forms rapidly and is almost unerring. On the contrary, incorrect preliminary verbal information leads to disorganisation of the process of skill formation (9).

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It is well known that differentiation of time plays an important part in various forms of human activity. This

may be said about work which is especially connected with the use of high-speed mechanisms, musical activity and sports in which timing, speed and succession of reactions are of decisive importance.

A number of experimental studies connected with elucidation of the role of feedback in reflecting the temporal parameters of athletic movements were conducted in our laboratory. V. D. Palyga made a successful attempt to elucidate the positive role played by information in perception of the duration and speed of various forms of gymnastic movements. By means of specially constructed devices and apparatus he tried to find the most rational conditions of organisation of feedback ensuring faultlessness of exercising connected with a correct appraisal of duration and speed.

The experimental material obtained by him shows that return afferentation is an absolutely necessary condition for the correctness of a gymnastic exercise and durability of athletic skills. This afferentation may vary in modality, but is the most effective in cases where the modality corresponds to the typological peculiarities of the subjects (33).

Information of a second signal character is especially productive: under conditions of correct organisation it ensures not only the speed of formation and durability of athletic skills, but also their transfer to an entirely new situation (34), (35).

* * *

Antecedent excitation which causes a preliminary tuning of the analyser in unison with the acting stimulus as a matter of feedback accounts for the high productivity of reflective activity which is corrected by signals about changes taking place in the surroundings.

In a number of experimental studies we succeeded in showing the extraordinary fruitfulness of the conception of antecedent reflection in the psychology of perception of time which is in its nature a model of the most clearly pronounced dynamics of objective reality. It may be assumed that the anticipation image of the temporal characteristics of the acting stimuli forms in the process of the motor accompaniment which is an important peculiarity of the reflection of time (7), (8). By reproducing

a certain succession of the stimuli, their duration and speed, the combined motorium is an important prerequisite for the emergence of antecedent reflection which is correlated with the model and is corrected as a matter of feedback (11).

Following the suggested propositions L. V. Vishnyova undertook to elucidate the role and importance of the anticipation image which reflects the temporal parameters of the motor process in the formation of gymnastic skills. She has found that productive training of gymnastic skills is always connected with a positive function of antecedent reflection which may be of the character of either excitation or inhibition. The latter is particularly important in athletic activity. The data obtained by Vishnyova show that the anticipation image, first-signal or second-signal, often characterised by interaction of first- and second-signal factors, assumes particular importance in cases where formation of gymnastic skills encounters great difficulties. She observed such a picture, in particular, in subjects born blind and therefore completely deprived of the activity of the visual analyser in mastering gymnastic skills. These data are of considerable practical importance (36), (37), (38).

* * *

The motor accompaniment which is a source of feedback and of formation of the anticipation image in the process of reflection of time is not always observed. In a number of experimental studies we have established that it undergoes a certain reduction under conditions of habituation.

Our subjects were a group of university students (undergraduate and postgraduate) and instructors who for a number of days listened to various musical melodies and rhythms and reproduced their temporal pattern by means of a telegraph key on a kymograph drum. For the purpose of fixing the combined motor habits which characterise perception of the temporal characteristics of the acting stimulus we recorded on an oscillograph the movements of their upper extremities and in some cases also of their tongues by means of a special electrode placed in the oral cavity.

The resultant material shows that with exercise in perception and reproduction of rhythms the motor

accompaniment is somewhat reduced and becomes increasingly less pronounced. This is due to a certain inhibition of the combined motorium occurring as a result of adaptation to the acting stimulus. This extinction of the motor accompaniment is sometimes observed in the course of one day after several experiments. In some cases it requires several days, i.e., a considerable number of experiments.

However, after a certain interruption (of several days) the combined motorium is somewhat activated and its role becomes very clear again. In individual subjects the picture of the motor accompaniment in no way differs from the picture observed in the first experiments. This is a result of disinhibition of the movements due to cessation of adaptation.

On the other hand, after repeated exercises the subjects master the skill of reproducing the perceived temporal stimulus to such an extent that they no longer need the anticipation model and correction as return afferentation or need them but very little (13).

The motor accompaniment may be of a conditioned reflex character. In a number of subjects it is observed under conditions of reproduction of the rhythmic order of the stimuli to oneself: when a subject mentally reproduces a musical rhythm he heard before, his extremities perform a number of movements resembling the afore-described picture. These movements join the movements of the tongue, which perform corrective functions. This is attested by the oscillograms we have obtained (13). It is very probable that in ordinary time reading this conditioned-reflex motoricity plays a very positive role, stimulated by ideas of some habitual rhythmic action.

All of the cited experimental material received in our laboratory in recent years warrants the assumption that the motor accompaniment forming as a matter of feedback acts as a model of the temporal parameters of the acting stimulus, which ensures the adequacy of reproduction.

The anticipation image of the stimulus on which reproduction orients itself forms on the basis of the combined motorium. This is one of the essential mechanisms of time perception.

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